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MECHANICAL-PROPERTY EVALUATIONS OF NEWLY DEVELOPED STRUCTURAL MATERIALS

L. G. Beall, Jr., and W. S. Hyler

Battelle Memorial Institute

TECHNICAL REPORT AFML-TR-66-155

April, 1966

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FOREWORD

This report was prepared by Battelle Memorial Institute under Contract No. AF 33(615)-2494. This contract was performed under Project No. 7381, "Materials Applications", Task No. 738106, "Materials Information Development". The work was administered under the direction of the Air Force Materials Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, by Mr. Marvin Knight, project engineer.

This yearly report covers work conducted from April 15, 1965 to March 15, 1966. This manuscript was released by the authors June 10, 1966 for publication as an RTD Technical Report.

Among those who cooperated in the research and/or the preparation of this technical report were: Mr. Clayton L. Harmsworth of the AF Materials Laboratory; and Messrs. James E. Campbell, William S. McCain, Charles H. Hickman, Jr., and Edward A. Eldridge, of Battelle Memorial Institute.

This report has been reviewed and is approved.

D. A. Shinn
Chief, Materials Information Branch
Materials Application Division
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July 18, 1966

Gentlemen:

Subject: Contract AF 33(615)-2494

In accordance with the provisions of the subject contract and distribution list received from the Air Force Systems Command, forwarded herewith is one copy of the following report.

Technical Report No. AFML-TR-66-155, "Mechanical Property Evaluations of Newly Developed Structural Materials".

Very truly yours,

L G Beall

L. G. Beall
Structural Materials Engineering

LGB:ng
Enc. (1)

ABSTRACT

The major objectives of this research program are to evaluate newly developed structural materials of potential Air Force weapons systems interest and then to provide data-sheet-type presentations of mechanical data. The first year's effort, covered in this report, has concentrated on TD Nickel, HP 9-4 steels, AFC-77 steel, and Lockalloy (62Be-38Al).

The mechanical properties investigated included tensile, compression, shear, bend, fracture toughness, fatigue, creep, and stress corrosion at appropriate temperatures.

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INTRODUCTION

Background

Increased performance requirements of Air Force weapons systems make the selection of materials having optimum characteristics vitally important. Frequently the requirements are such that the most suitable alloys are either in the final development stages or have just become commercially available.

However, since these alloys are new, there may not be adequate mechanical-property information available for aircraft and aerospace companies to acknowledge them as candidate materials. The Air Force in recognition of this need initiated a program at Battelle for obtaining engineering data on selected newly developed alloys. The expectation is that such data could serve to stimulate interest in the exploitation of these materials for advanced structures.

Objective

The primary objective of this program is to obtain comparative engineering data for newly developed structural alloys using standardized tests procedures, where available, for standard test conditions.

The first years' effort, covered in this report, has concentrated on six combinations of materials and/or material treatments. The materials are:

(1) TD Nickel sheet
(2) HP 9-4-25 plate
(3) HP 9-4-45 plate
(4) AFC-77 sheet (two heat treatments)
(5) Lockalloy (62Be-38Al) sheet.

The metallurgical conditions selected for evaluation are described in a later section.

The program approach was to search published literature and to contact the metal producers for pertinent data. Tests were scheduled to fill in gaps in the existing information. Then, upon completion of each material evaluation plans call for issuing a uniform mechanical-property data sheet with associated graphs. Detailed information concerning the properties of interest and test techniques are described in subsequent sections.

II

SCOPE

Test Materials

This section contains information supplied by the vendors for all the materials acquired during the first year of the program. Included for each material are the source, condition, chemistry, and mechanical-property data as furnished.

TD Nickel Sheet

Source: E. I. du Pont de Nemours and Company, Inc.

Form: 0.060-inch sheet

Heat: 1254 and 1287

Condition: Stress relieved

Chemical Composition, percent

Heat:	1254	1287
Carbon	0.0012	0.0035
Titanium	<0.001	<0.001
Iron	<0.01	0.01
Chromium	<0.01	<0.01
Cobalt	<0.01	<0.01
Copper	<0.001	0.003
Sulfur	0.0013	<0.001
ThO_2	2.3	2.3

Vendor Test Report

Tensile[a]

Heat	Test Temperature, F	Ultimate Tensile Strength, ksi	0.2% Yield Strength, ksi	Elongation in 1 Inch, percent
1254	RT	63.6	45.8	16.5
	2000	13.6	12.9	5.0
1287	RT	64.3	48.6	17.0
	2000	13.2	12.4	6.0

(a) Transverse orientation.

Stress Rupture[a]				
Heat	Test Temperature, F	Stress, ksi	Life, hr	Elongation in 1-Inch, percent
1254	2000	5.0	>20	2.1
1267	2000	5.5	>20	4.8

(a) Transverse orientation.

HP 9-4-25 Plate

Source: Republic Steel Corporation

Form: 0.25-inch plate

Heat: 3931021 air melt, VAR

Condition: Hot rolled and annealed

Chemical Composition, percent			
Carbon	0.27	Nickel	8.28
Manganese	0.27	Chromium	0.41
Phosphorus	0.004	Molybdenum	0.49
Sulfur	0.009	Vanadium	0.07
Silicon	0.01	Cobalt	3.90

HP 9-4-45 Plate

Source: Republic Steel Corporation

Form: 0.25-inch plate

Heat: 3931141 air melt, VAR

Condition: Hot rolled and annealed

Chemical Composition, percent			
Carbon	0.46	Nickel	7.73
Manganese	0.19	Chromium	0.32
Phosphorus	0.003	Molybdenum	0.29
Sulfur	0.008	Vanadium	0.09
Silicon	0.01	Cobalt	4.03

AFC-77 Sheet

Source: Crucible Steel Company of America

Form: 3-1/2-inch plate

Heat: 74096

Condition: Hot rolled and annealed

Chemical Composition, percent			
Carbon	0.15	Nickel	0.12
Manganese	0.24	Chromium	13.84
Phosphorus	0.010	Vanadium	0.23
Sulfur	0.018	Molybdenum	5.05
Silicon	0.21	Cobalt	13.44
	Nitrogen 0.06		

Lockalloy (62Be-38Al) Sheet

Source: The Beryllium Corporation

Form: 0.062-inch sheet

Lot: 65-6, 65-13, 65-7

Condition: Annealed 24 hours at 1100 F and etched

Etching Solution: 15 percent nitric acid by volume
2 percent hydroflouric acid by volume
Balance - deionized water

Vendor Test Report

		Room-Temperature Tensile					
		Ultimate Tensile Strength, ksi		0.2% Yield Strength, ksi		Elongation, percent	
Lot	Unit	L	T	L	T	L	T
65-6	372 H-B	50.9	50.3	36.0	36.2	8.5	8
65-7	389 H-C	51.6	51.3	33.5	34.2	11.5	9.5
65-7	407 H-A	51.8	52.6	37.5	37.2	14.5	14.5
65-7	407 H-C	52.0	51.1	37.1	36.8	13.5	12
65-13	902 H-A	47.1	46.9	37.85	38.0	5.5	6
65-13	902 H-G	46.1	46.2	36.9	37.8	4	4.5
65-13	902 H-F	46.3	45.6	36.8	37.6	5.9	5.8
63-13	902 H-I	46.0	45.7	37.5	37.0	5.5	5.3

Processing and Heat Treating

Processing and heat treating at Battelle, where required, was conducted according to vendor recommendations. The treatments used for each of the materials in the program were as follows:

TD Nickel Sheet

(1) Evaluated in the as-received, stress-relieved condition.

HP 9-4-25 Plate

(1) Treatment of machined specimens

(a) Normalized 1 hour at 1600 F in protective atmosphere and air cooled

(b) Austenitized 1 hour at 1525 F in protective atmosphere and oil quenched

(c) Double tempered 2 hours each at 1025 F.

HP 9-4-45 Plate

(1) Treatment of machined specimens

(a) Normalized 1 hour at 1600 F in protective atmosphere and air cooled

(b) Austenitized 1 hour at 1475 F in protective atmosphere

(c) Quenched in salt bath at 475 F and tempered at 475 F for 7 hours.

AFC-77 Sheet

(1) Hot rolling of billet (processed at Battelle)

(a) Soaked at 1900 F for 2 hours

(b) Heated to 2100 F and transferred to rolls within 1/2-hour

(c) Rolled with maximum reduction per pass less than 15 percent of thickness obtained for preceding pass

(d) Minimum rolling temperature 1600 F (reheated to 2000 F when necessary)

(e) Sixty-two passes were required to reduce 3-1/2-inch billet to 0.11-inch sheet

(f) Pickled in 10 percent H_2SO_4 at 150 F

(2) Treatment of rolled sheet for machineability

(a) Austenitized 15 minutes 1900 F in protective atmosphere and oil quenched

(b) Double tempered 2 hours each 1400 F

(3) Treatment for Group I (machined specimens)

(a) Austenitized 15 minutes 1900 F in protective atmosphere and oil quenched

(b) Subzero quenched at -100 F for 1/2 hour

(c) Double tempered 2 hours each at 700 F

(4) Treatment for Group II (machined specimens)

(a) Austenitized 15 minutes 1900 F in protective atmosphere and oil quenched

(b) Subzero quenched at -100 F for 1/2 hour

(c) Double tempered 2 hours each at 1100 F.

Lockalloy (62Be-38Al) Sheet

(1) Evaluated in the as-received annealed and etched condition.

Mechanical Properties

The various mechanical properties of prime interest for each of the designated materials are as follows:

(1) Tensile [longitudinal (L) and transverse (T) at room temperature (RT) and elevated temperature (ET)].

(a) Ultimate tensile strength, F_{tu}

(b) Tensile yield strength, F_{ty}

(c) Elongation, e_t

(d) Reduction in area, RA (when applicable)

(e) Modulus of elasticity, E_t

(2) Compression (L and T at RT and ET)

(a) Compression yield strength, F_{cy}

(b) Modulus of elasticity, E_c

(3) Impact (at RT and ET when applicable)

(4) Fracture toughness, K_{Ic} (at RT and ET)

(5) Bend (at RT and cryogenic temperatures)

(a) Minimum radius

(b) Ductile to brittle bend-transition temperature

(6) Shear (L and T at RT)

(a) Ultimate shear strength, F_{su}

(7) Axial fatigue (at RT and ET)

(a) $K_t = 1$, $R = 0.1$, Lifetime: 10^3 through 10^7 cycles

(b) $K_t = 3$, $R = 0.1$, Lifetime: 10^3 through 10^7 cycles

(8) Creep and stress rupture (selected ET)

(a) Stress for 0.2 or 0.5 percent deformation in 100 hours and in 1000 hours

(b) Stress for rupture in 100 hours and in 1000 hours

(9) Stress corrosion (RT)

(a) 80 percent F_{ty}, 1000 hours maximum

(10) Coefficient of thermal expansion

(11) Density.

III

EXPERIMENTAL PROCEDURE

Specimen Identification

A straightforward numbering system was used for specimen identification. Coding consists of a number indicating the type of test, followed in appropriate cases by a letter signifying specimen orientation (L for longitudinal or T for transverse), which is followed by the specimen number. The final number denotes the location on the original test panel from which the specimen was taken. Numbers representing the type of test are as follows:

(1) Tension
(2) Compression
(3) Creep
(4) Shear
(5) Fatigue
(6) Fracture toughness
(7) Stress corrosion
(8) Thermal expansion
(9) Bend.

For example, 2-T-5 is a transverse compression specimen cut from Panel Location 5.

Specimen designs used in this program are shown in Figures 1 through 12. These specimens conform to dimensional and tolerance specifications outlined in relevant ASTM standards, in AIA publication ARTC-13, or in MAB publication MAB-192-M. The applicable standards are covered later in the discussions of procedures for conducting each type of test. The 1-inch-gage-length tensile specimen (Figure 2) was used only for the Lockalloy study. This was to take full advantage of the limited amount of available test material and to be compatible with data obtained from other sources also on specimens with a 1-inch gage length. Full sheet thickness specimens were used except where otherwise noted.

Test Description

Tension

Procedures used for carrying out tensile tests were those recommended in ASTM Methods E8-61T and E21-58T as well as in Federal Test Method Standard 151a (Method 211.1). Three specimens were tested at each temperature to determine ultimate tensile strength, yield strength (0.2% offset), elongation, and reduction in area. The modulus of elasticity was derived from load-strain curves plotted by an autographic recorder during each test.

All tensile tests were carried out in Baldwin Universal testing machines. These machines are calibrated at frequent intervals in accordance with ASTM Method E4-64 to assure loading accuracy within ±0.2 percent. The machines are equipped with integral automatic strain pacers and autographic strain recorders.

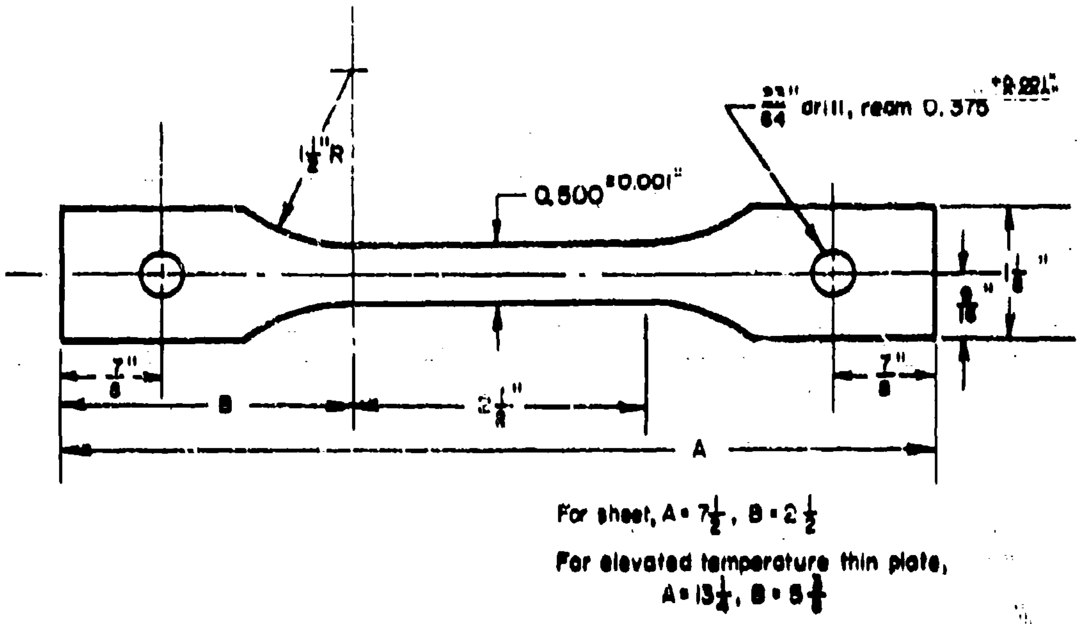


FIGURE 1. SHEET AND THIN-PLATE TENSILE SPECIMEN

2-Inch Gage Length

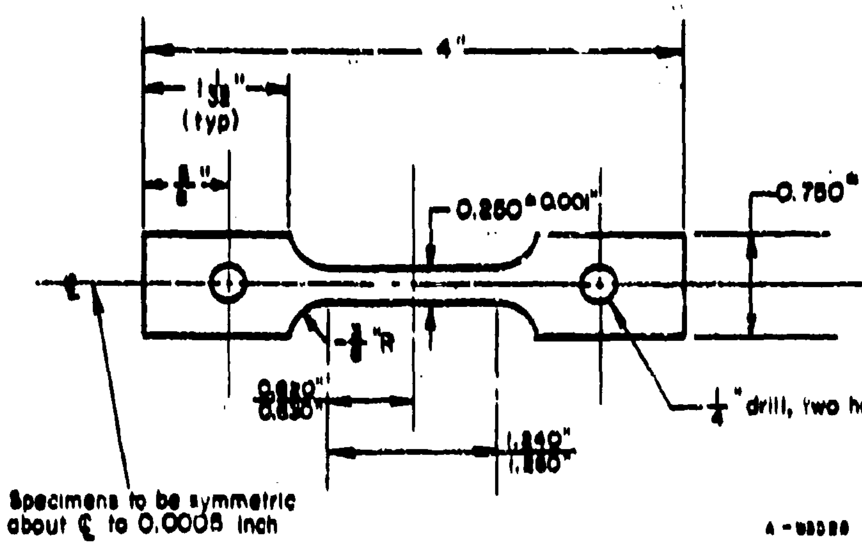


FIGURE 2. SHEET TENSILE SPECIMEN

1-Inch Gage Length

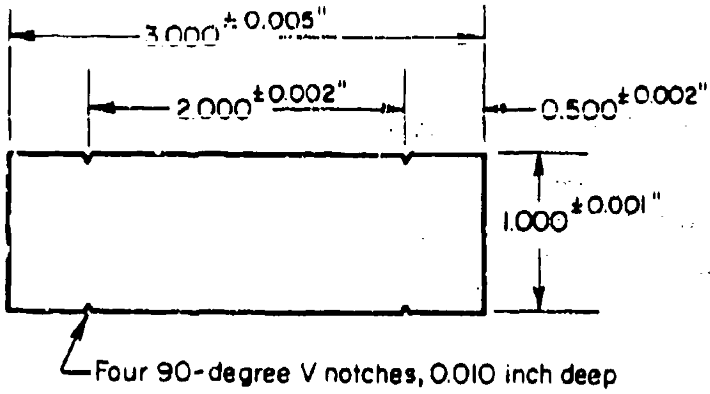


FIGURE 3. SHEET COMPRESSION SPECIMEN

Note: (1) Ends must be flat and parallel to within 0.0002 inch
(2) Surface must be free from nicks and scratches.

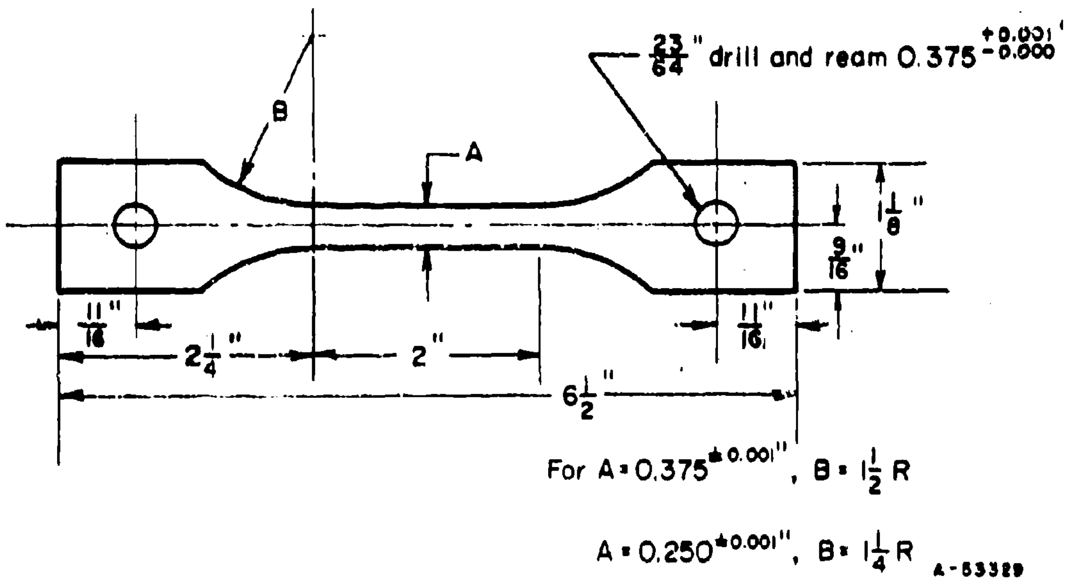


FIGURE 4. SHEET CREEP SPECIMEN

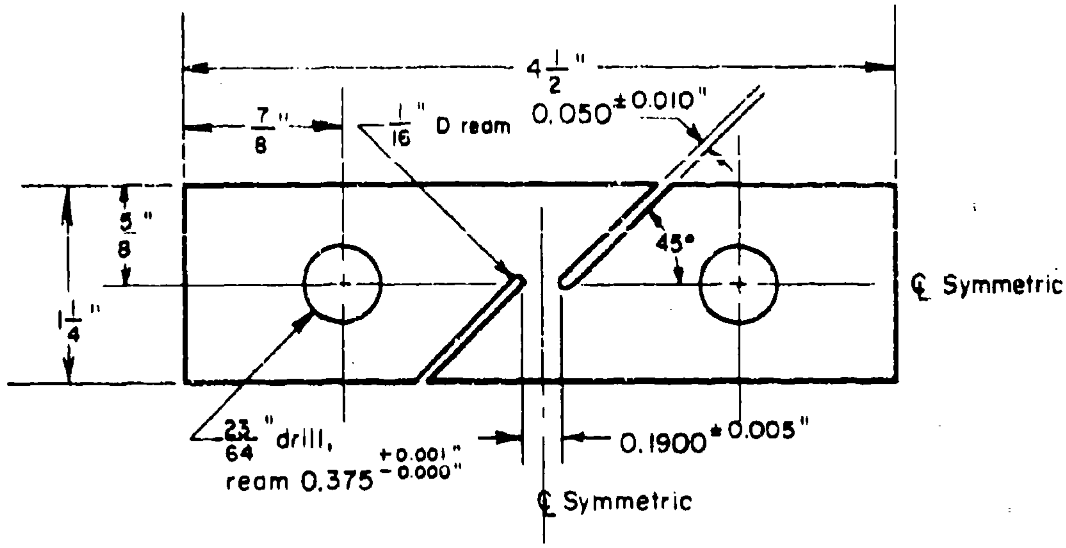
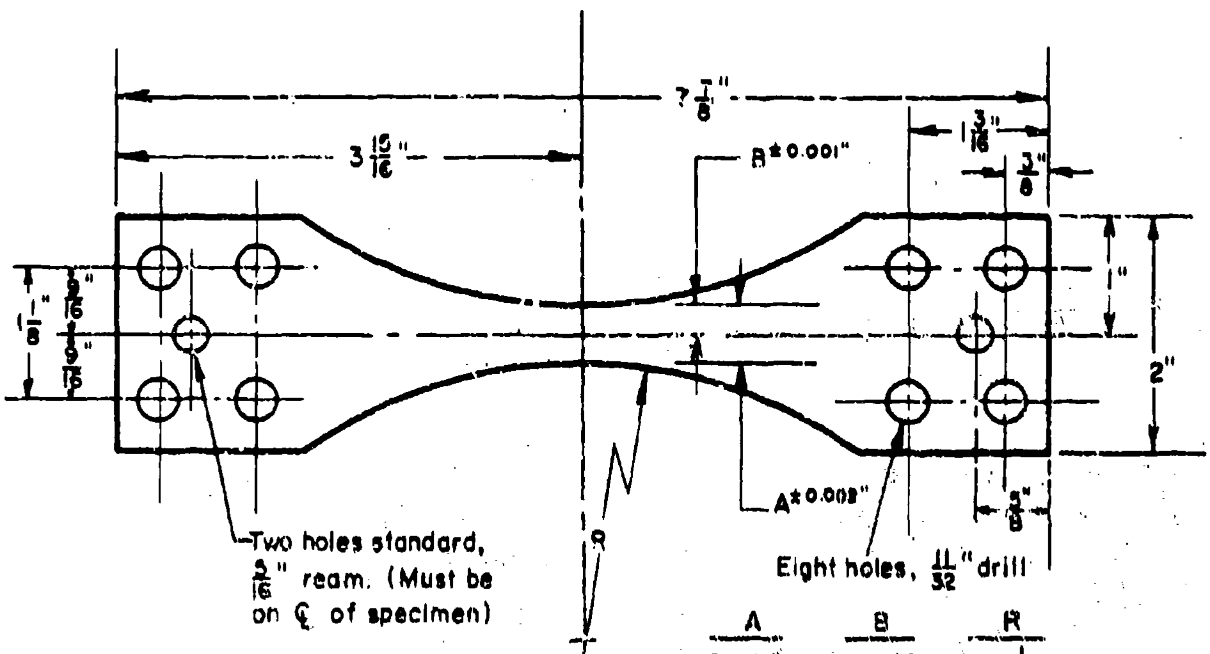


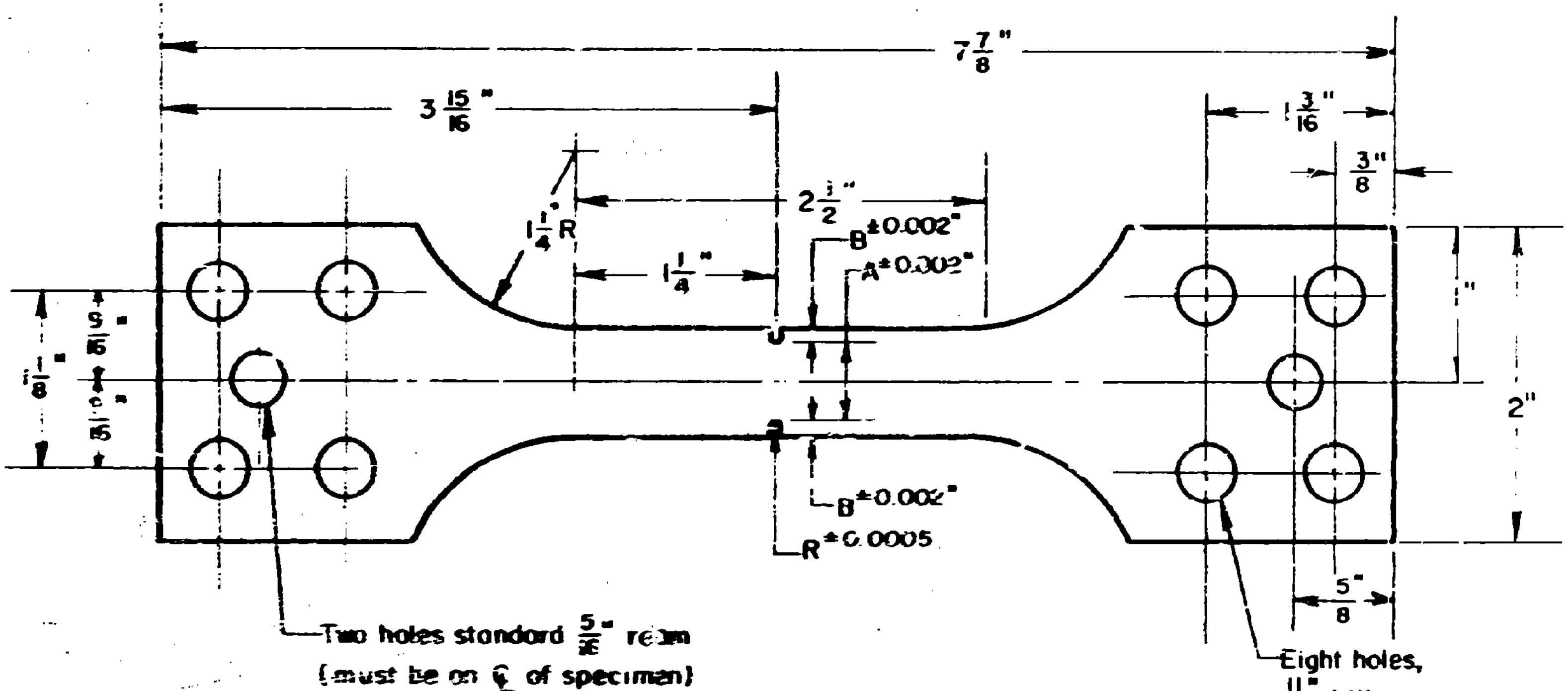
FIGURE 5. SHEET SHEAR TEST SPECIMEN



A	B	R
0.900	0.450	5 1/2
0.500	0.250	4
0.250	0.125	3

A - 33330

FIGURE 6. UNNOTCHED SHEET FATIGUE SPECIMEN



K_t = 3 (Neuber-Peterson)

A	B	R
0.900	0.175	0.0625
0.375	0.125	0.0312

A-51331

FIGURE 7. NOTCHED (K_t = 3) SHEET FATIGUE SPECIMEN

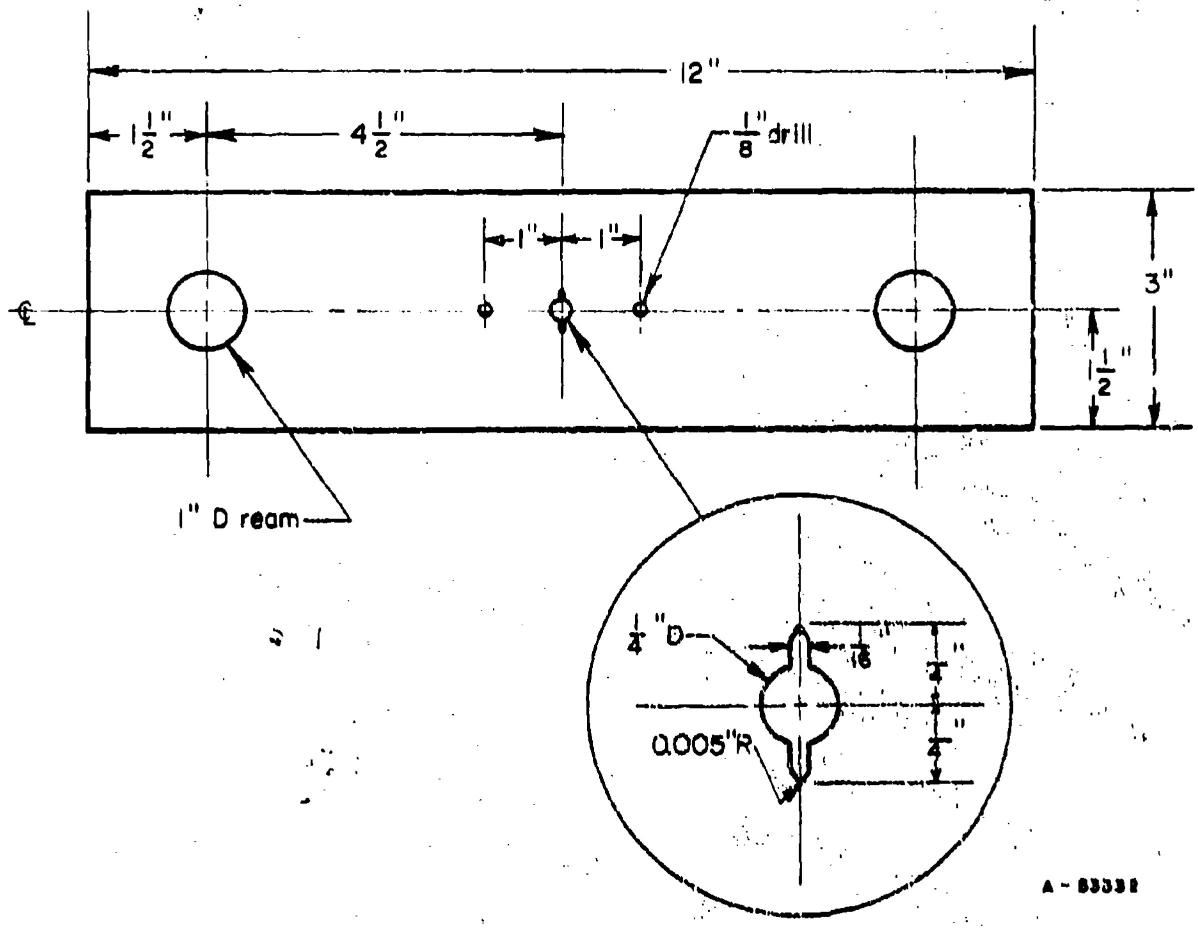


FIGURE 8. CENTER-NOTCH FRACTURE-TOUGHNESS SPECIMEN

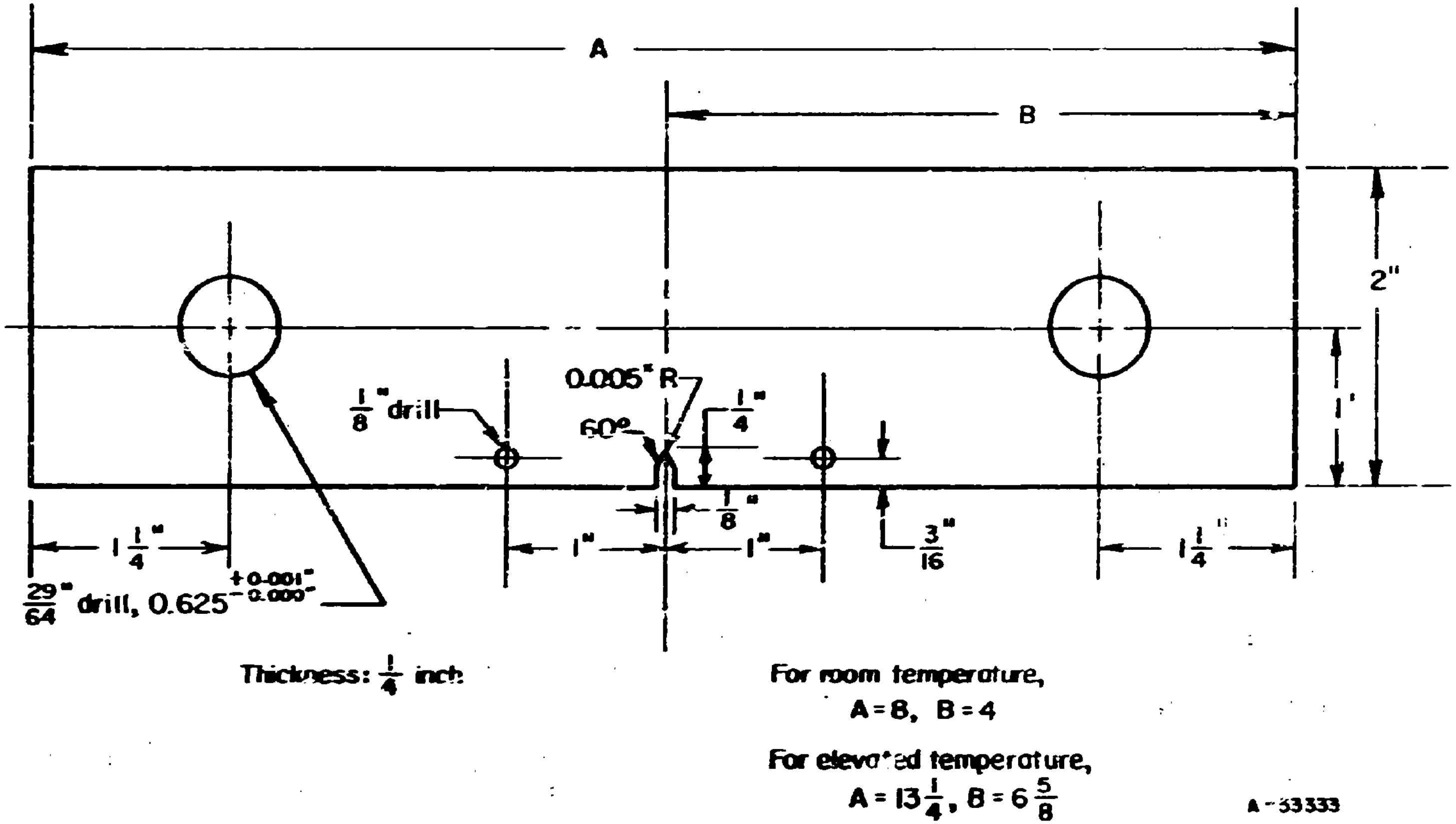


FIGURE 9. EDGE-NOTCH FRACTURE-TOUGHNESS SPECIMEN

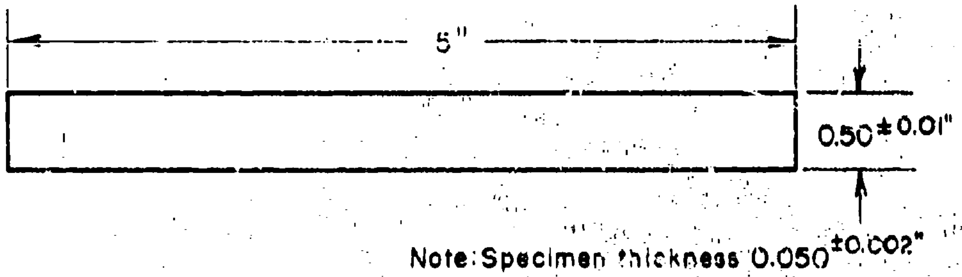


FIGURE 10. SHEET STRESS-CORROSION SPECIMEN

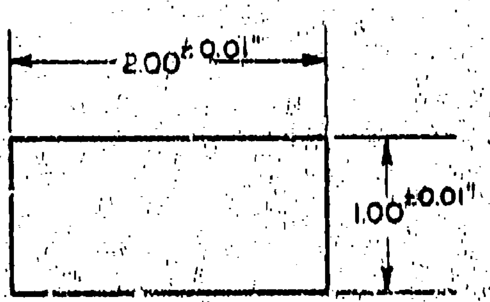
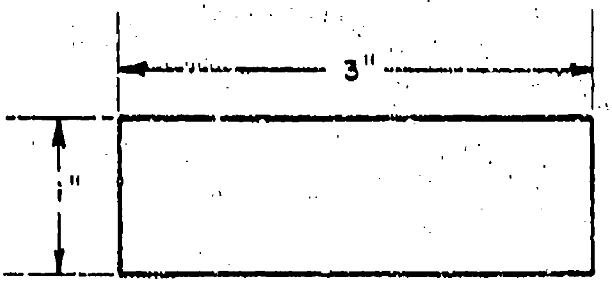


FIGURE 11. THERMAL-EXPANSION SPECIMEN



A-83334

FIGURE 12. SHEET BEND SPECIMEN

The sheet and thin-plate tensile-specimen configurations (Figures 1 and 2) conformed to type F2 in Method 211.1 except that the grip sections contained holes for pin loading. Pin-loaded specimens are preferred because they permit better alignment and facilitate gripping in furnaces for elevated-temperature tests.

Specimens tested at elevated temperatures were heated in standard wire-wound resistance-type furnaces. Each furnace was equipped with a Foxboro controller capable of maintaining the test temperature to within ±5 F of the control temperature over a 2-inch gage length. Chromel-Alumel thermocouples attached to the specimen gage section were used to monitor temperatures. Each specimen was held at temperature for at least 20 minutes before starting a test.

An averaging-type linear-differential-transformer extensometer with extensions to bring the transformer unit out of the furnace in elevated-temperature testing was used to measure strain. The extensometer conformed to ASTM 83-64T Classification B-1 having a sensitivity of ±0.0001 inch/inch. The strain rate in the elastic region was maintained at 0.005 inch/inch/minute. After yield, the head speed was increased to 0.1 inch/minute until fracture.

Compression

Procedures for carrying out compression tests were as recommended in ASTM Method E9-61 along with temperature-control provisions of E21-58T. All tests were conducted in Baldwin Universal testing machines using a North American Aviation-type compression fixture as shown in Figure 13 for studies to 1000 F. A forced-air circulating furnace was used for specimen heating. Specimen temperature was maintained by means of a Wheelco pyrometer. Three Chromel-Alumel thermocouples attached to the compression fixture were used to monitor temperature. Temperatures were held to within ±3 F of test temperature with this equipment. A modified version of this fixture having graphite lateral support blocks as shown in Figure 14 was used for tests to 2000 F. In this case, wire-wound furnaces were used with controls as described in the previous section on tensile tests. Either of these fixtures can be adjusted to accommodate specimens of various thicknesses up to 1/4 inch.

The extensometer employed for the compression work was quite similar to that used in tensile testing. In this case the extension arms were fastened to the specimen at small notches spanning a 2-inch gage length (see Figure 3). The output from the extensometer microformer was fed into a load-strain recorder to provide autographic load-strain curves. During testing, the strain rate was adjusted to 0.005 inch/inch/minute. Three specimens were tested at each temperature to determine the compressive yield strength (0.2% offset) and the compressive modulus of elasticity.

Shear

Single-shear specimens of the type specified in Standard Test Procedure ARTC-13-5-1 were used for these studies (see Figure 5). Three longitudinal specimens and three transverse specimens were used to determine the ultimate shear strength at room temperature for each material.

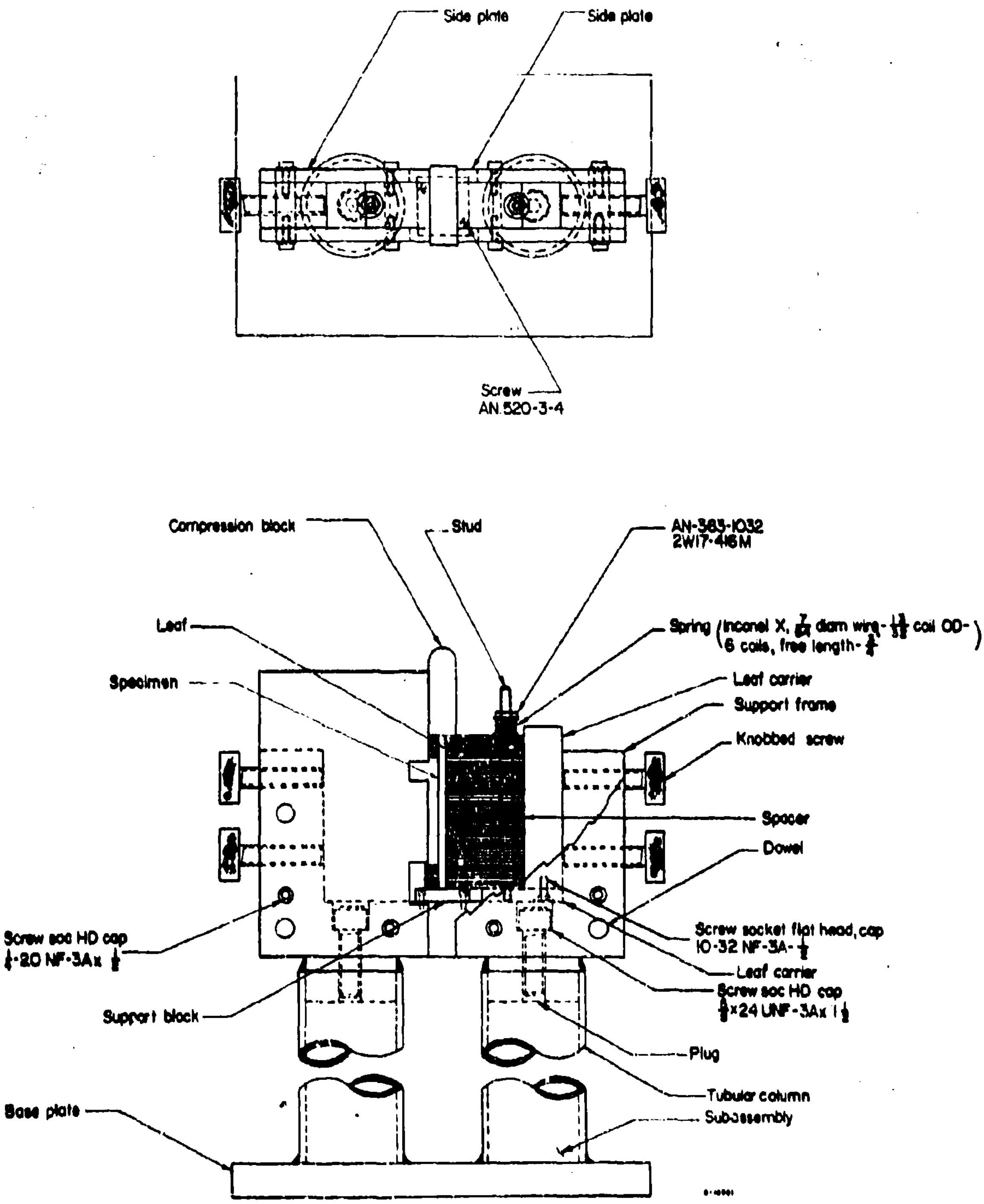
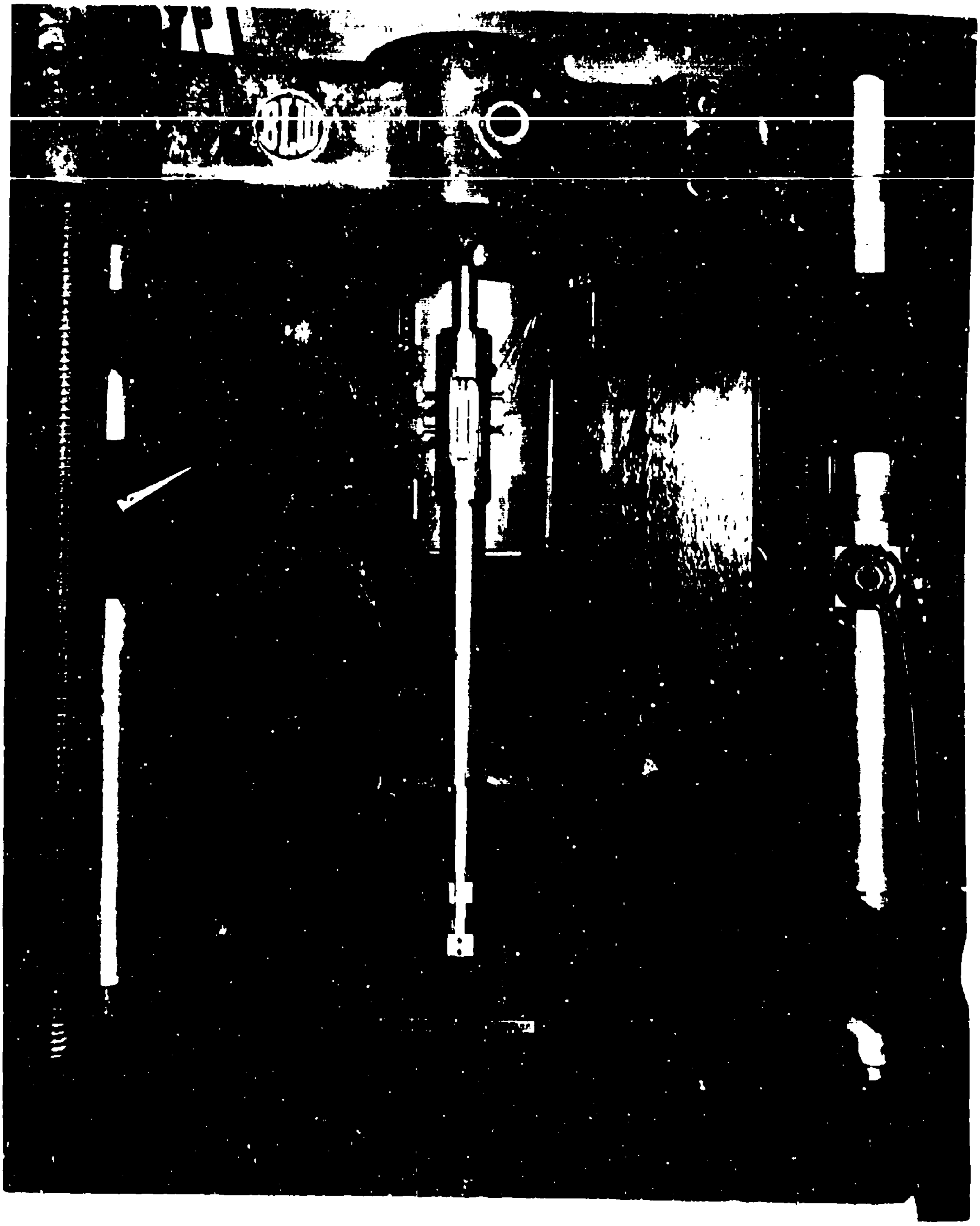


FIGURE 13. NORTH AMERICAN AVIATION-TYPE COMPRESSION FIXTURE

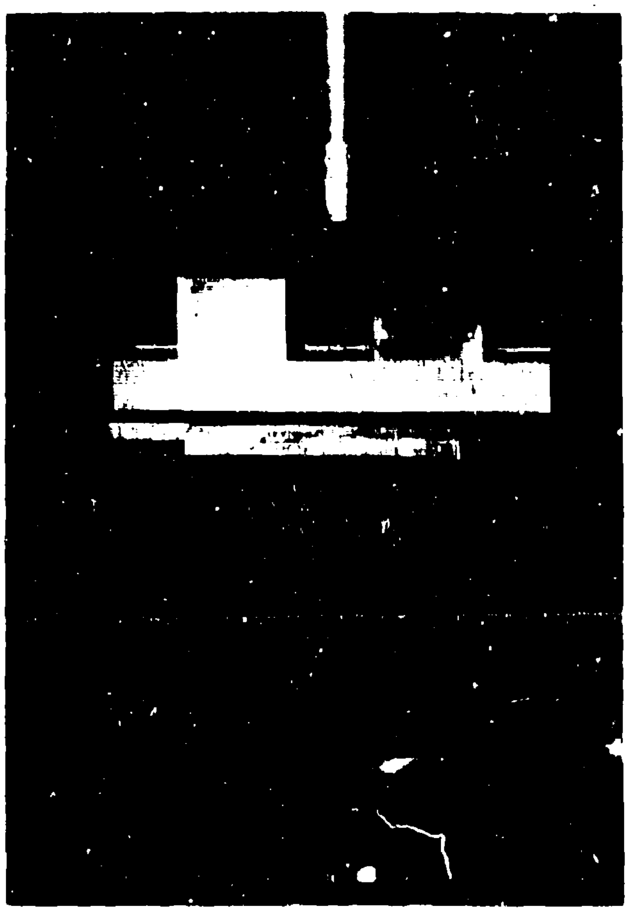


30878

FIGURE 14. FIXTURE DESIGNED FOR COMPRESSION TESTS TO 2000 F

Bend

The procedure used for conducting bend tests is described in Report MAB-192-M. As shown in Figure 15, the specimen was placed in a rigid three-point loading fixture. Bending cups of various sizes were used to determine the minimum bend radius at room temperature. Additional tests were conducted below room temperature (limited to -110 F) to determine the transition temperature for a given bend radius.



30876

FIGURE 15. BEND TEST FIXTURE

Fracture Toughness

Two types of fracture-toughness specimens were used for the sheet and thin-plate studies. A center-notch specimen as shown in Figure 8 was used for thin sheet and a single-edge-notch specimen as shown in Figure 9 was used for thin plate. The dimensions of these specimens were in accordance with the latest recommendations of the ASTM Committee on Fracture Toughness. These specimens had several things in common. First, each was designed for axial-loading tests. Second, grip ends for pin-type loading were provided (to promote the best possible alignment). And third, the specimens were precracked at the root of the notches under fatigue loads. The precracking was carried out with the maximum stress limited to 60 percent of F_{ty}. This stress level has been found to produce a precrack of the desired length in tests of short duration while minimizing plastic deformation at the leading edge of the crack.

All tensile tests on precracked fracture-toughness specimens were carried out in Baldwin Universal testing machines. As shown in Figure 16, a flat spring-type compliance gage with extension arms was used in conjunction with an autographic recorder to provide a load-deformation curve. The pop-in load for materials susceptible to brittle fracture was determined from this curve.

In certain ductile materials, net section stresses at pop-in or fracture may exceed the ASTM yield criterion. In these cases rather than noting individual stress intensity factors, it is considered more useful to report a notch strength value with the understanding that the notch is a fatigue crack. When these values are entered on the data sheet, they will be footnoted with the crack geometry conditions at failure.

At least three specimens were used for each room-temperature and elevated-temperature investigation.

Computations of G_{Ic} or K_{Ic} values for materials where pop-in occurs are carried out in accordance with procedures recommended by Srawley and Brown.(1)*

Creep and Stress Rupture

Standard dead-weight-type creep-testing frames, as shown in Figure 17, were used for the creep and stress-rupture tests. These machines are calibrated to operate well within the accuracy requirements of ASTM Method E139-58T.

Specimens similar to those employed in tension tests (see Figure 4) were used for the creep and stress-rupture studies. Such a specimen prepared for testing is shown in Figure 18 along with pretest and posttest specimens. As shown, a platinum strip "slide-rule" extensometer is attached for measuring creep strain and three Chromel-Alumel thermocouples are attached to the gage section for temperature measurement. Extensometer measurements were made visually through windows in the furnace (see Figure 17) by means of a filar micrometer microscope in which the smallest division equals 0.00005 inch.

*References are given on page 67

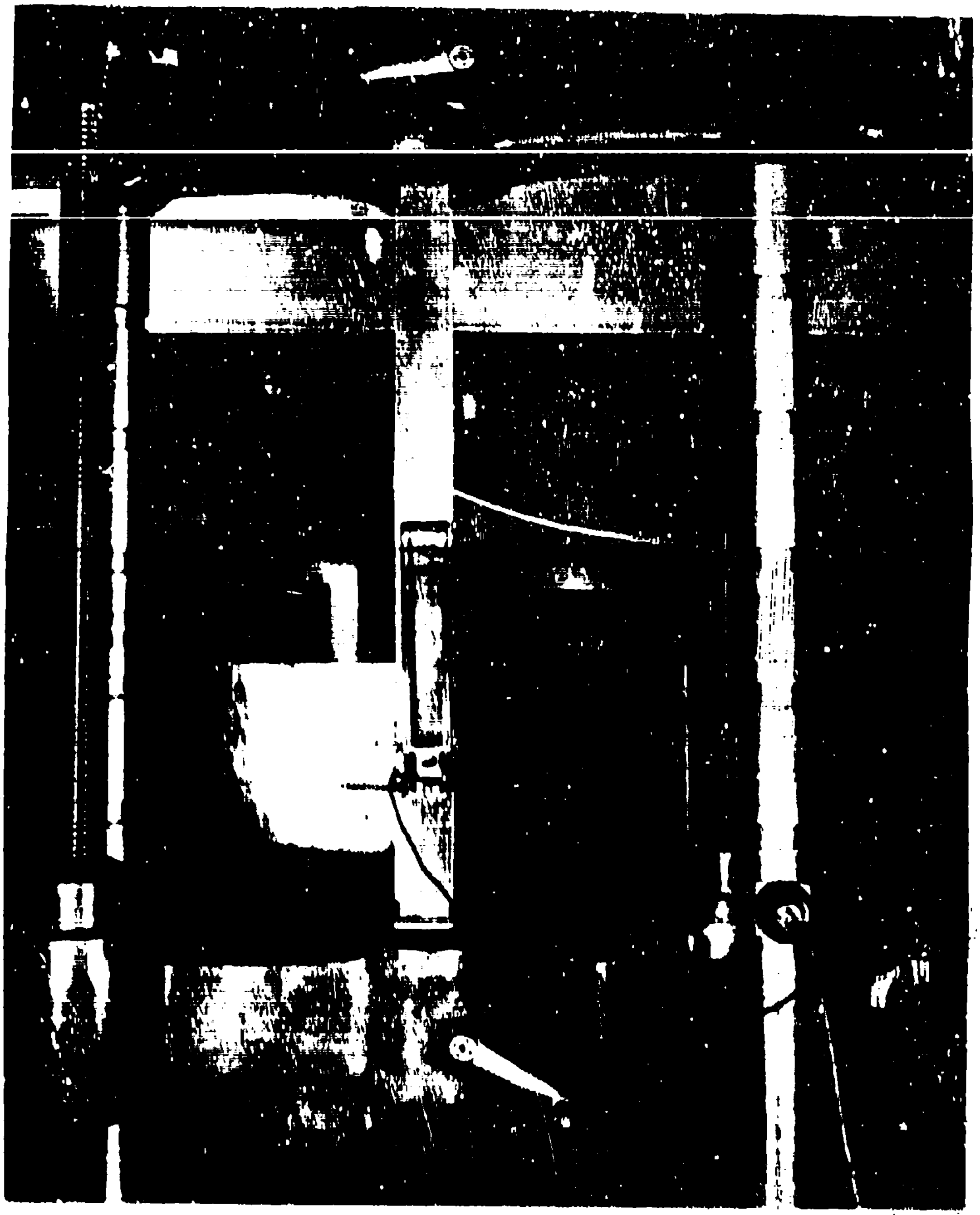


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FIGURE 16. CENTER-NOTCH FRACTURE-TOUGHNESS SPECIMEN IN BALDWIN UNIVERSAL TESTING MACHINE

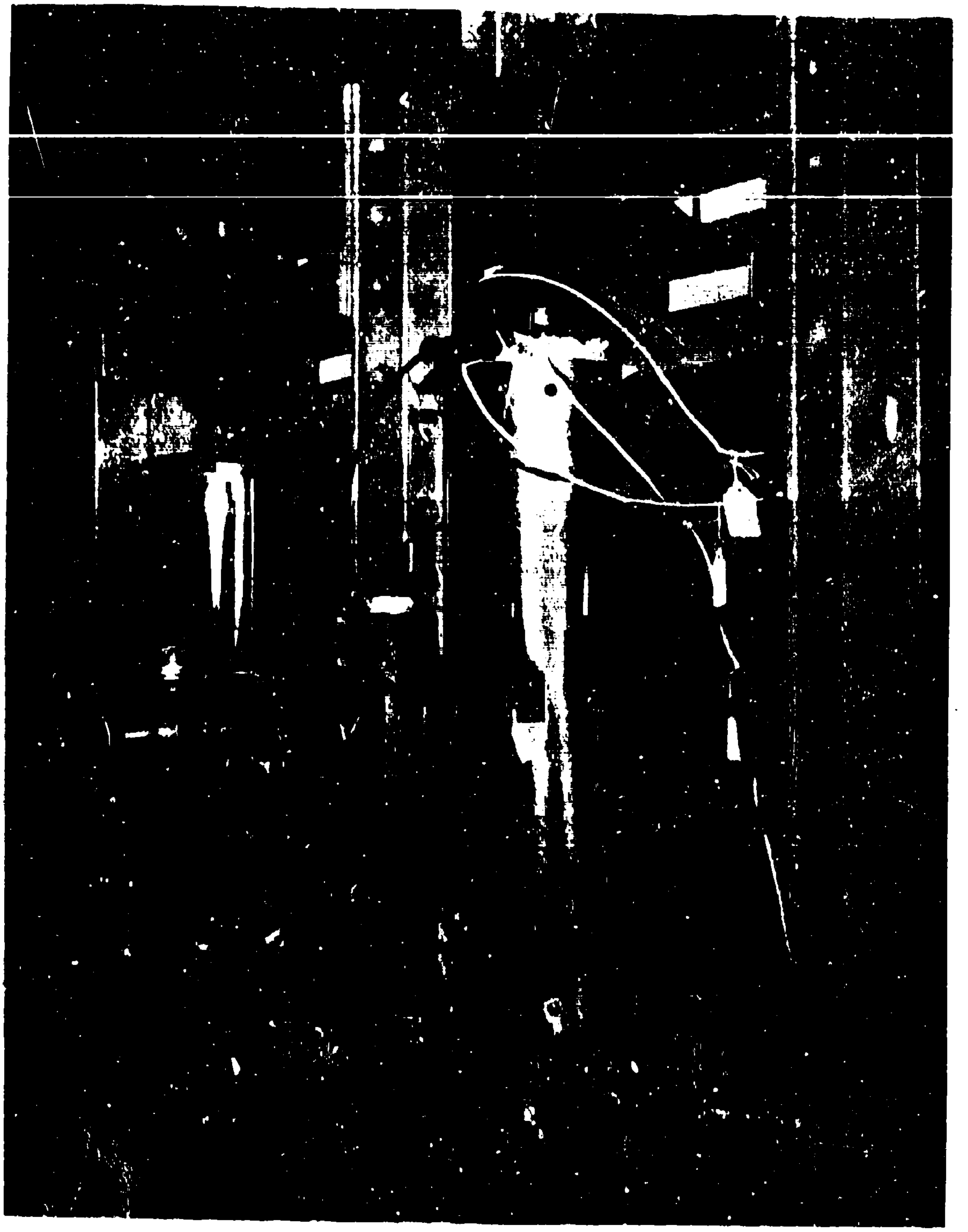

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FIGURE 17. CREEP-TESTING FRAME WITH FURNACE AND MICROMETER MICROSCOPE

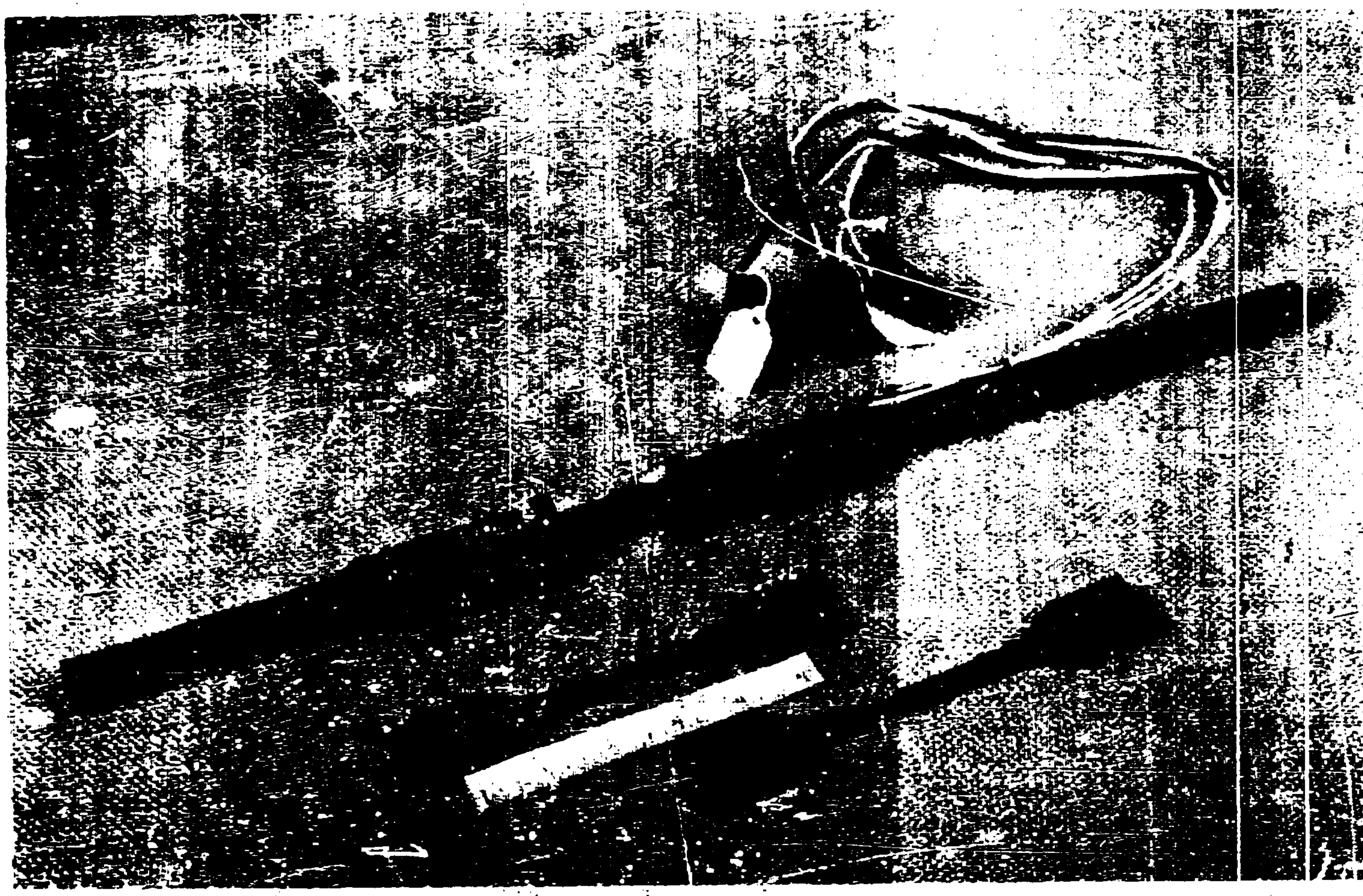

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FIGURE 18. AN INSTRUMENTED CREEP SPECIMEN ALONG WITH PRETEST AND POSTTEST SPECIMENS

The furnace was of conventional Chromel A wire-wound design with taps along the side to allow for correcting small temperature differences. Furnace temperature was maintained to within ±2 F by Foxboro controllers in response to signals from the centrally located thermocouple. The temperature of a specimen under test was stabilized for at least 1/2 hour prior to loading.

For each temperature condition creep and stress-rupture data were obtained for 100 and 1000 hours using as many specimens as necessary to obtain precise information. The percent creep deformation obtained was dependent upon the material under test. In most instances either 0.2 or 0.5 percent elongation stress-time curves were defined.

Stress Corrosion

Seven specimens of each alloy were tested for susceptibility to stress-corrosion cracking by alternate immersion in 3-1/2 percent sodium chloride solution at room temperature.

Specimens were prepared for testing by degreasing with acetone. Where a surface film remained from heat treating, it was abraded off one side and the adjacent long edge on five of the seven specimens, and left intact on the other two.

Each specimen was placed into a four-point loading fixture (see Figure 19) and deflected to a stress corresponding to 80 percent of the tensile yield strength. The specimen was electrically insulated from the fixture by means of glass or sapphire rods. Deflection for a given maximum fiber stress was calculated by $y = \frac{\sigma(3\ell^2 - 4a^2)}{12dE}$, where y = deflection, σ = maximum fiber stress, ℓ = distance between outer load points, a = distance between outer and inner load points at one end, d = thickness of specimen, and E = modulus of elasticity for the specimen material.

1581

FIGURE 19. SPECIMEN INSTALLED IN STRESS-CORROSION TEST FIXTURE

Each stressed specimen was suspended on an alternate-immersion test unit as shown in Figure 20. This unit alternately immersed specimens in the sodium chloride solution for 10 minutes and held them above the solution to dry for 50 minutes. Tests were continued to the first sign of cracking or for 1000 hours, whichever occurred first.

Specimens on alternate-immersion test were given frequent low-power microscopic examinations to detect cracks. At the first sign of cracking the specimen was removed. At the conclusion of a test, selected samples were sectioned and metallographically examined for any indication of cracks. Representative samples in which cracks have been found were also given a metallographic examination to establish the type and extent of cracking.

Thermal Expansion

Linear-thermal-expansion measurements were performed in a recording dilatometer with specimens protected by a vacuum of about 2×10^5 mm of mercury. The unit used in this program for sheet specimens at temperatures to 2000 F is shown in Figures 21 and 22. Figure 21 shows a calibration specimen mounted in the support structure with the vacuum envelope, radiation shields, and heater element removed. These items are shown assembled in Figure 22. In this apparatus a sheet-type specimen is supported between two graphite structures inside a tantalum-tube heater element. On heating, the differential movement of the two structures caused by specimen expansion, results in the displacement of the core in a linear-variable differential transformer. The output of the transformer is recorded continuously as a function of specimen temperature. The entire assembly is enclosed in a vacuum chamber.

The furnace is controlled to heat at the desired rate, usually 5 F per minute. Errors associated with measurements in this apparatus are estimated not to exceed ±2 percent. This is based on calibration with materials of known thermal-expansion characteristics.

Fatigue

Two types of fatigue equipment were used to perform the axial tension fatigue tests on notched and unnotched sheet and thin-plate specimens (specimens shown in Figures 6 and 7). Selection of a test machine was made primarily on the basis of the required load level. Tests on sheet were conducted in 5000-pound-capacity Krouse machines as shown in Figure 23. Tests on thin plate or tests requiring a low cycle rate were conducted in Research Incorporated electrohydraulic machines. Figure 24 shows a specimen being installed in the 20,000-pound-capacity Research Incorporated machine. Figure 25 shows the 50,000-pound-capacity R. I. machine along with the controls for both units.

The Krouse axial-load equipment is mechanically driven and provides loads on a constant-deflection basis. The Krouse machines normally operate at about 1725 cpm. They are equipped with hydraulic load maintainers to stabilize the mean load should some creep deformation occur. The frequency of cycling of the Research Incorporated hydraulic fatigue machines is variable to beyond 2000 cpm depending on specimen rigidity. These machines operate with closed-loop deflection, strain or load control. Under load control, used in this program, cyclic loads were automatically maintained (regardless of the required amount of ram travel) by means of load-cell feedback signals.

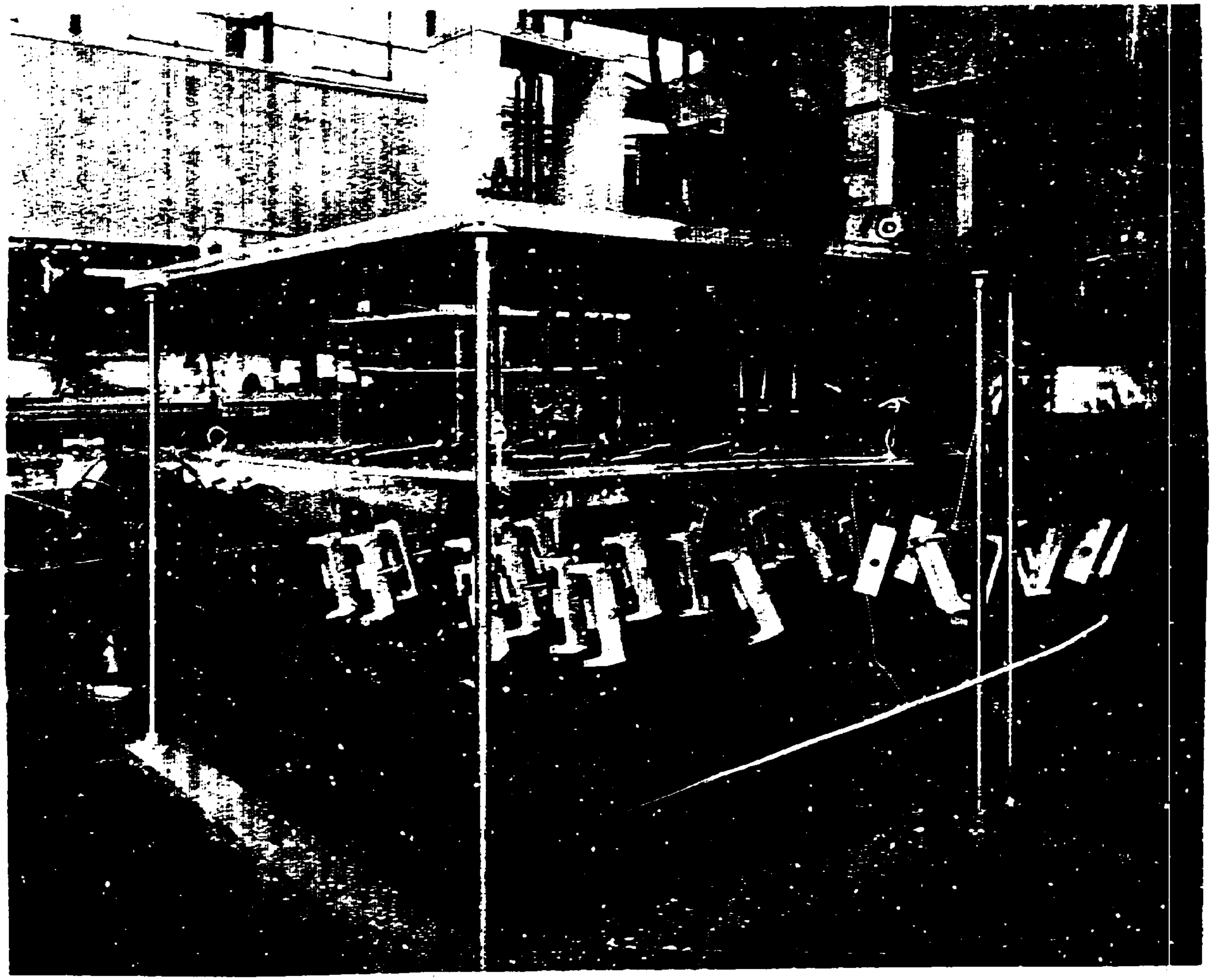

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FIGURE 20. ALTERNATE-IMMERSION UNIT FOR STRESS-CORROSION STUDIES

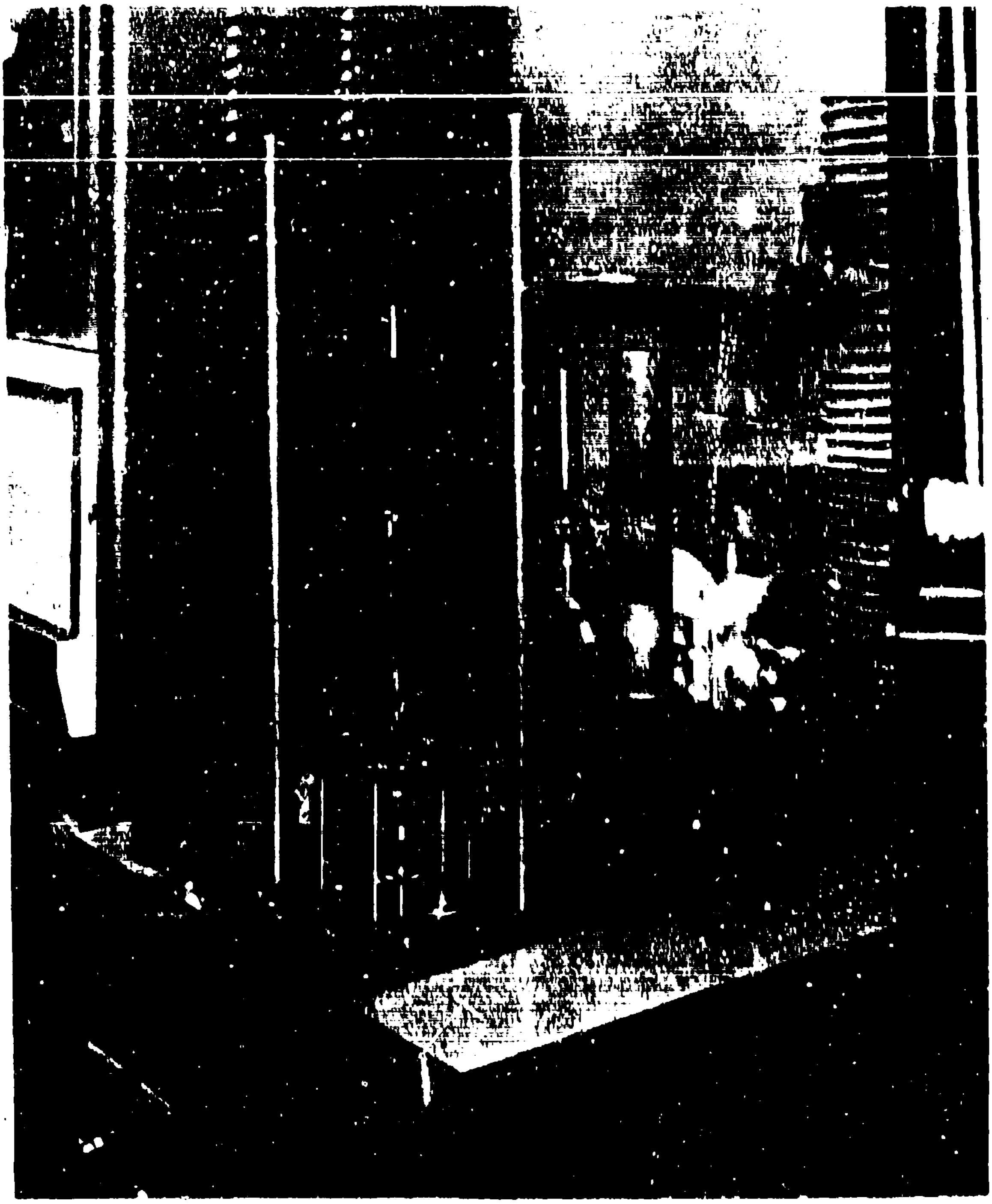

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FIGURE 21. RECORDING DILATOMETER APPARATUS SHOWING SPECIMEN-SUPPORT STRUCTURE

25153

FIGURE 22. RECORDING DILATOMETER APPARATUS

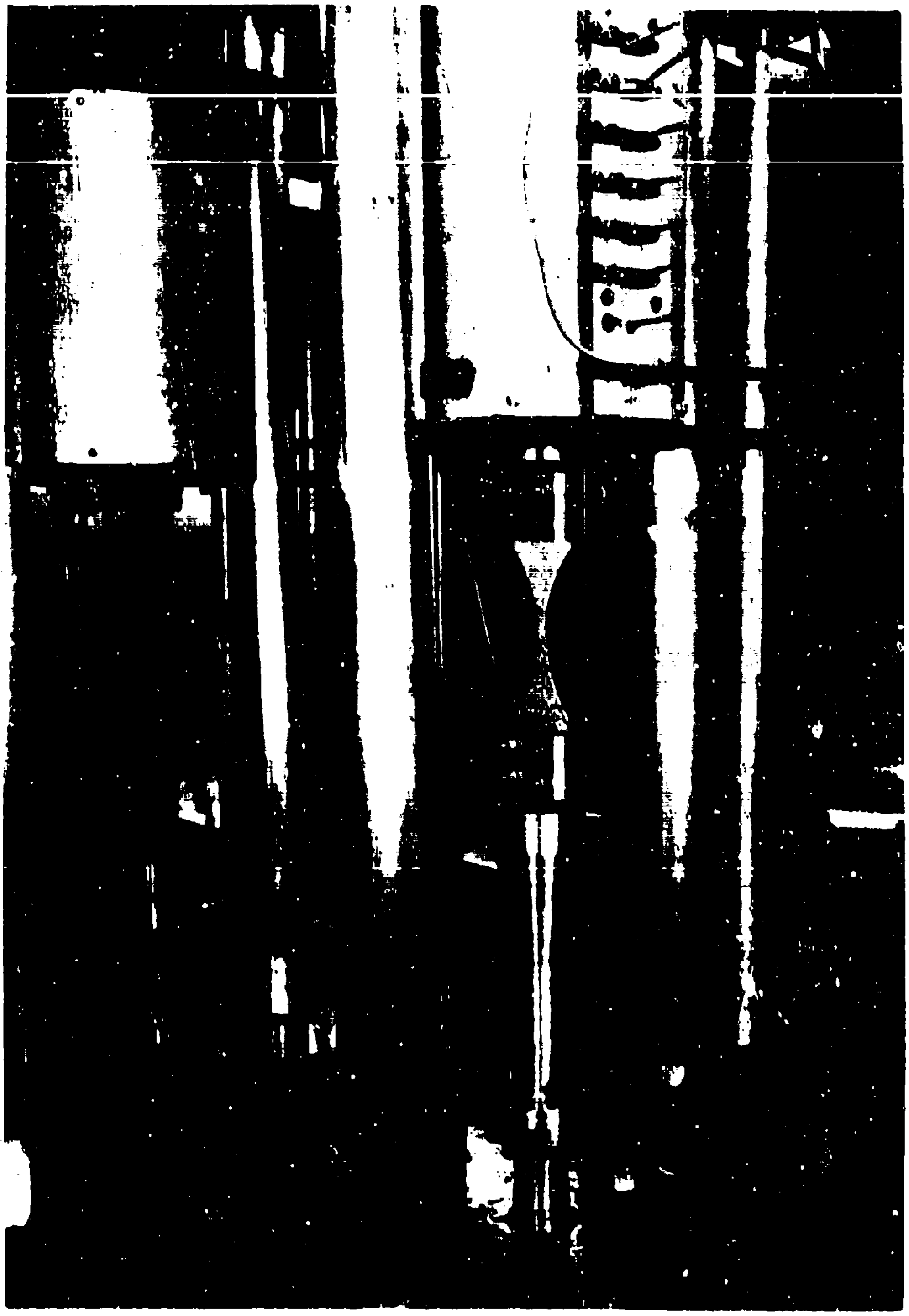

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FIGURE 23. KROUSE FATIGUE MACHINE WITH NOTCHED AND UNNOTCHED SPECIMEN INSTALLED FOR ROOM-TEMPERATURE TEST

FIGURE 24. INSTALLATION OF SPECIMEN IN 20,000-POUND-CAPACITY RESEARCH INCORPORATED ELECTROHYDRAULIC TEST MACHINE

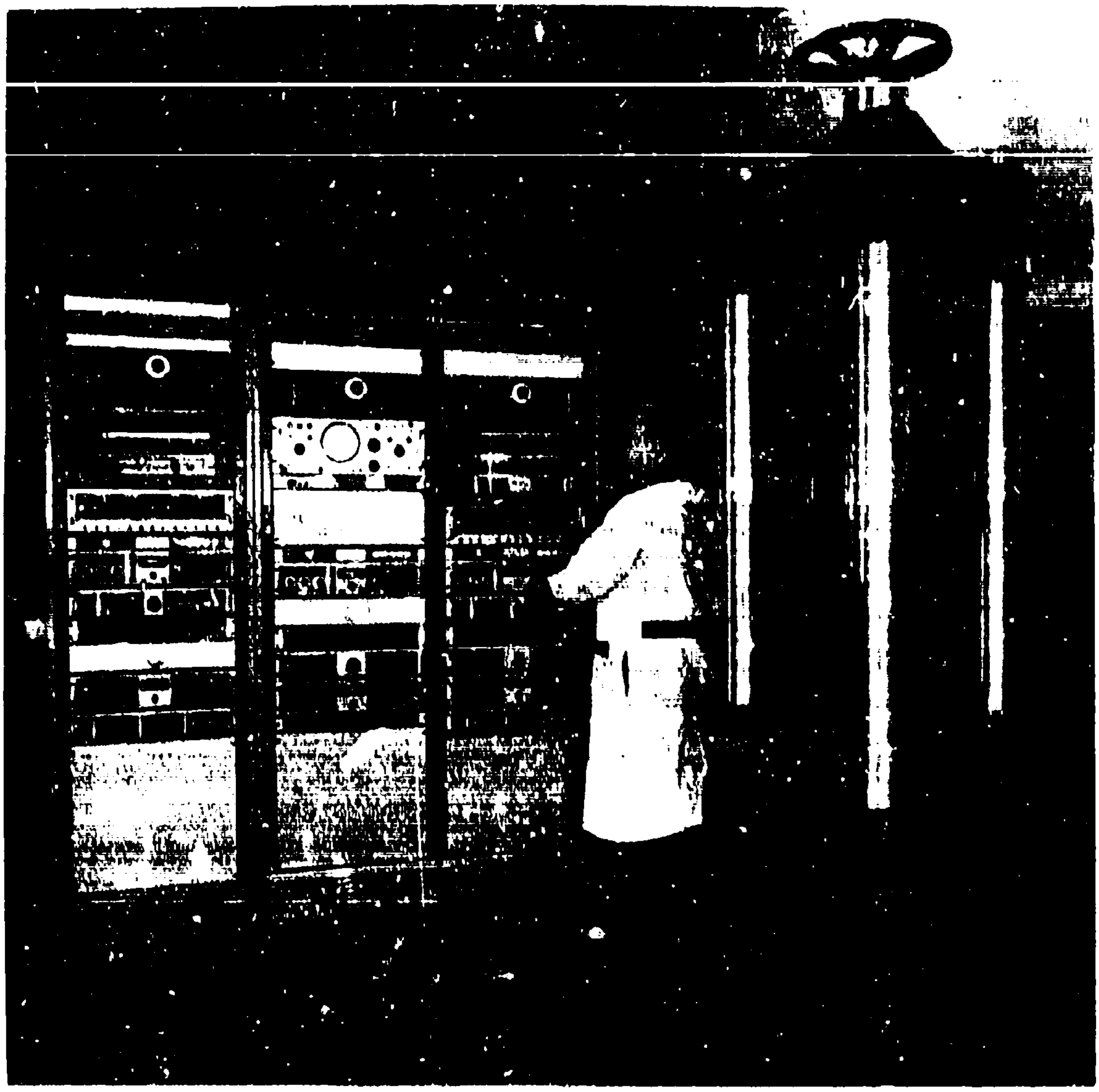

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FIGURE 25. CONTROL CONSOLE FOR 20,000-, 50,000-, AND 200,000-POUND-CAPACITY RESEARCH INCORPORATED FATIGUE MACHINES

50,000-Pound Machine Shown.

The calibration and alignment of each machine are checked periodically. In each case the dynamic-load-control accuracy is better than ±3 percent of the test load.

For elevated-temperature studies electrical-resistance wire-wound furnaces of conventional design were used to heat the specimens. Three Chromel-Alumel thermocouples, placed near the center of each specimen at 1-inch intervals, were employed in furnace calibration. During a fatigue test, the center thermocouple was used in conjunction with a Foxboro controller to adjust electrical input to the furnace. The thermal gradient along the test section was continuously monitored by the other two thermocouples. During tests the center of the specimen was held to within ±5 degrees of the control temperature.

After machining, and heat treating where required, the edges of all fatigue specimens (except for Lockalloy) were polished according to Battelle's standard practice prior to testing. The unnotched specimens were held against a rotating drum covered with emery paper and polished using a kerosene lubricant. Successively finer grits were used as required to produce a surface finish of about 10 rms. The notched specimens were held in a fixture and polished with a slurry of oil and Alundum grit applied liberally to a rotating wire until a similar finish was achieved. The Lockalloy specimens were machined and hand finished to 12 to 16 rms in the beryllium machining facility. A shadowgraph optical comparator was used for measuring the test sections of each polished specimen and for inspection of the root radius in the case of notched specimens.

The stress ratio for all tests was R = 0.1. Stresses for notched (K_t = 3.0) and unnotched specimens were selected so that S-N curves were defined between 10^3 cycles and 10^7 cycles using approximately 10 specimens for each set of fatigue conditions.

Status of Material Evaluations

All the alloys designated for evaluation during the first year of this program have been acquired. All these materials were obtained in the desired product form except for AFC-77 steel. This alloy was not available as sheet in small quantity. Therefore, a piece of 3-1/2-inch plate was procured and rolled to sheet using Battelle facilities. The machining of test specimens was completed for all materials except Lockalloy. Only fracture-toughness specimens remain to be machined from this alloy. Heat treating of materials subsequent to machining has been accomplished. Mechanical-property evaluations for all alloys are in progress. The evaluation of TD Nickel is completed. Individual data-sheet-type presentations of mechanical data will be issued upon completion of the evaluation of each material. The status of each evaluation along with the expected date for issuing a completed data sheet is indicated in the following paragraphs.

TD Nickel Sheet

The mechanical evaluation of this alloy is complete. Information obtained for this alloy is presented in this report. The completed data sheet will be issued by the end of April, 1966.

HP 9-4-25 and HP 9-4-45 Plates

All room- and elevated-temperature tensile and compression tests and room-temperature shear tests have been completed. Stress-corrosion tests are in progress for both the 25 and 45 material. Creep and stress-rupture tests are well under way for the 25 alloy and have been started for the 45 alloy. Fatigue testing has been started. Tensile, compression, and shear data for both materials are presented in this report. The completed data sheet for each of these alloys is scheduled for the end of June, 1966.

AFC-77 Sheet

Mechanical property studies of AFC-77 for the two tempering treatments described earlier are under way. Preliminary data will become available by June, 1966. The completed data sheet will be issued by the end of July, 1966.

Lockalloy (62Be-38Al) Sheet

The processing of Lockalloy is being carried out in the same manner as for the design-allowables studies under NASA Contract NAS 8-11448.(2) The data generated will be coordinated with that obtained from this previous evaluation. The Battelle studies are designed to develop fracture toughness, fatigue, creep, stress-rupture, and stress-corrosion information. Preliminary data will be available in July, 1966, with the data sheet to be issued by the end of August, 1966.

Additional Materials

Five materials have been designated for evaluation during the second year of the contract. These materials will, for the first few months, be processed concurrently with those presently under evaluation. The selected materials are:

Alloy	Product Form
7039 aluminum	1-inch plate
2021 aluminum	1-inch plate
Beryllium	Cross-rolled sheet
HP 9-4-25	Forging
HP 9-4-45	Forging

The initial literature search and organization of data for these materials are completed. Contacts have been made with the material suppliers, and arrangements are being made for the procurement of appropriate quantities.

Results

For convenience, the results of the various tests conducted as of March 15, 1966, for TD Nickel are presented in Appendix I; for HP 9-4-25 in Appendix II; and, HP 9-4-45 in Appendix III. The initial table in each appendix is a data sheet summarizing data obtained, with blanks for evaluations that are scheduled. The summary sheet is followed

by data tables for individual tests. The series of data tables are followed by a series of figures showing these data in graphical form. A final technical report will be issued at the end of the second year of effort that will summarize all data presented here and additional data generated for these and other designated materials.

APPENDIX I

TD NICKEL SHEET DATA[a]

TABLE I. DATA SHEET FOR TD NICKEL SHEET

Condition: stress-relieved
Thickness: 0.060 inch

Properties	Temperature, F RT	1600	1800	2000
Tensile				
F_{tu} (longitudinal), ksi	63.6	21.4	17.9	14.7
F_{tu} (transverse), ksi	63.8	20.6	17.1	13.3
F_{ty} (longitudinal), ksi	46.2	21.2	17.7	14.1
F_{ty} (transverse), ksi	45.6	20.3	16.8	12.9
e_t (longitudinal), percent in 2 in.	14.5	5.0	5.0	8.0
e_t (transverse), percent in 2 in.	14.5	3.0	3.0	3.0
E_t (longitudinal), psi x 10^6	16.9	10.7	9.1	8.2
E_t (transverse), psi x 10^6	17.8	10.3	8.8	8.6
Compression				
F_{cy} (longitudinal), ksi	42.1	20.9	17.2	13.6
F_{cy} (transverse), ksi	49.4	20.3	16.1	12.8
E_c (longitudinal), ksi	16.0	9.4	9.9	7.7
E_c (transverse), ksi	18.4	9.7	9.9	7.4
Impact				
(Bar) ft-lb(3)*	30	--	30	--
Fracture Toughness	(b)	--	--	--
Bend				
(Transverse)	Sharp[c]	--	--	--
Shear F_s				
(Longitudinal), ksi	57.9	--	--	--
(Transverse), ksi	58.4	--	--	--
Axial Fatigue				
(Transverse)				
10^3 (K_t = 1) (R = 0.1), ksi	63.0	23.0	19.0	--
10^5 (K_t = 1) (R = 0.1), ksi	57.5	19.8	16.0	--
10^7 (K_t = 1) (R = 0.1), ksi	45.0	15.0	11.5	--
10^3 (K_t = 3) (R = 0.1), ksi	61.0	22.5	17.0	--
10^5 (K_t = 3) (R = 0.1), ksi	39.0	15.0	13.0	--
10^7 (K_t = 3) (R = 0.1), ksi	44.5	10.0	8.0	--
Creep				
(Transverse)				
0.2% elongation 100 hr, ksi	--	10.0	7.2	4.6
0.2% elongation 1000 hr, ksi	--	8.2	5.2	3.5[e]

TABLE I. (Continued)

Properties	RT	Temperature, F 1600	1800	2000
Stress Rupture				
Rupture 100 hr, ksi	--	11.0	7.8	5.4
Rupture 1000 hr, ksi	--	9.0	5.8	4.4
Stress Corrosion				
80 percent F_{ty} 1000 hr max	No cracks	--	--	-
Coefficient of Thermal Expansion				
60 to 2000 F		8.7×10^6 in./in./F		
Density[3, 4]		0.322 lb/in.^{3}		
Ductile to Brittle Bend-Transition Temperature, F		Lower than -100 F[d]		
Melting Temperature		2650 F[5]		

Notes: Thermal conductivity, Btu/ft^2/in./hr/°F at 70 F = 800 (3) (5)
500 F = 880
1100 F = 800
1500 F = 880
1700 F = 940

Electrical resistivity, microhm-cm (70 F) 7.6 (4) (5)

Specific heat, Btu/lb/F 0.106 (4) (5)

*References are given on page 67.

(a) Data are average values.

(b) Specimen failed in a ductile manner.

(c) Sharp bending Tup (75-deg angle), specimen unloaded bend angle over 100 deg; no cracks at RT.

(d) Sharp bending Tup (75-deg angle); no crack at -100 F

(e) Tentative; verification test in progress.

TABLE II. TENSILE RESULTS FOR TD NICKEL SHEET[a] AT FOUR TEMPERATURES

Specimen	0.2% Offset Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation in 2 Inches, percent	Tensile Modulus, psi x 10^6
		Longitudinal at Room Temperature		
1L-1	46.1	63.7	15.5	16.6
1L-2	46.2	63.7	13.0	17.0
1L-3	46.2	63.3	15.0	17.0
Average	46.2	63.6	14.5	16.9
		Transverse at Room Temperature		
1T-1	45.7	63.8	14.5	17.5
1T-2	45.6	63.8	14.5	17.9
1T-3	45.6	63.7	14.5	18.0
Average	45.6	63.8	14.5	17.8
		Longitudinal at 1600 F		
1L-4	21.0	21.1	5.0	10.5
1L-5	21.1	21.3	4.5	10.7
1L-6	21.5	21.7	5.5	10.9
Average	21.2	21.4	5.0	10.7
		Transverse at 1600 F		
1T-4	20.4	20.7	3.0	10.5
1T-5	20.1	20.5	3.0	9.8
1T-6	20.4	20.5	3.0	10.5
Average	20.3	20.6	3.0	10.3
		Longitudinal at 1800 F		
1L-7	17.7	17.6	5.0	9.1
1L-8	17.6	18.0	5.0	9.3
1L-9	17.8	18.0	6.0	9.0
Average	17.7	17.9	5.0	9.1
		Transverse at 1800 F		
1T-7	16.8	17.1	3.5	9.1
1T-8	16.8	17.0	--	8.5
1T-9	16.7	17.2	3.0	8.7
Average	16.8	17.1	3.0	8.8
		Longitudinal at 2000 F		
1L-10	14.3	14.7	8.0	7.7
1L-11	14.4	14.8	8.0	8.2
1L-12	14.1	14.6	8.0	8.8
Average	14.3	14.7	8.0	8.2
		Transverse at 2000 F		
1T-10	12.7	13.2	3.5	9.9
1T-11	12.8	13.3	3.0	8.3
1T-12	13.1	13.4	3.0	7.5
Average	12.9	13.3	3.0	8.6

(a) 0.0[illegible]-inch stress-relieved sheet.

TABLE III. COMPRESSION RESULTS FOR TD NICKEL SHEET[a] AT FOUR TEMPERATURES

Specimen	0.2% Offset Yield Strength, ksi	Compression Modulus, psi x 10^6
	Longitudinal at Room Temperature	
2L-1	42.3	15.5
2L-2	42.0	16.7
2L-3	42.0	15.8
Average	42.1	16.0
	Transverse at Room Temperature	
2T-15	49.3	18.3
2T-2	49.8	18.5
2T-3	49.2	18.5
Average	49.4	18.4
	Longitudinal at 1600 F	
2L-4	20.5	9.4
2L-5	20.6	9.9
2L-6	20.6	9.1
Average	20.9	9.5
	Transverse at 1600 F	
2T-4	20.3	9.9
2T-5	20.3	9.1
2T-6	20.4	10.1
Average	20.3	9.7
	Longitudinal at 1800 F	
2L-7	17.2	9.8
2L-8	17.3	10.5
2L-9	17.1	9.3
Average	17.2	9.9
	Transverse at 1800 F	
2T-7	16.3	10.0
2T-8	16.6	9.8
2T-9	15.5	10.0
Average	16.1	9.9
	Longitudinal at 2000 F	
2L-10	13.6	7.8
2L-11	13.5	8.0
2L-12	13.8	7.4
Average	13.6	7.7
	Transverse at 2000 F	
2T-10	12.7	7.7
2T-11	13.1	7.4
2T-12	12.6	7.1
Average	12.8	7.4

(a) 0.060-inch stress-relieved sheet.

TABLE IV. FRACTURE-TOUGHNESS RESULTS FOR TD NICKEL SHEET(a) AT ROOM TEMPERATURE

Specimen	Width Beyond Crack Tips(b), in.	Notch Strength(c), psi
5-1	2.145	57.3
5-2	2.240	57.4
Average	2.193	57.3

(a) 0.060-inch stress-relieved sheet; transverse specimens.
(b) Data on center notch precracked specimens. Nominal specimen width is 3 inches. The precracks produced by fatigue loading developed in a shear plane and, therefore, were not normal to the loading direction. Fractures were completely ductile and there was considerable reduction in thickness at the fractures. Therefore, data obtained were outside criteria for computing valid K_{IC} values.
(c) The notch strength (undetermined K_t since notch is a fatigue crack) is considerably higher than the room temperature F_{ty} (45.6 ksi) but less than the F_{tu} (63.8 ksi).

TABLE V. SHEAR TEST RESULTS FOR TD NICKEL SHEET(a) AT ROOM TEMPERATURE

Specimen		Ultimate Shear Strength, psi
	Longitudinal	
4L-1		57.5
4L-2		58.7
4L-3		57.4
Average		57.9
	Transverse	
4T-1		58.1
4T-2		59.2
4T-3		58.0
Average		58.4

(a) 0.060-inch stress-relieved sheet.

TABLE VI. RESULTS OF AXIAL-LOAD FATIGUE TESTS ON TD NICKEL SHEET[a] AT THREE TEMPERATURES

Specimen	Maximum Stress, ksi	Lifetime, kilocycles
	Room Temperature	
5-52	63	3.4
5-51	62	26
5-40	60	7.0
5-57	58.5	246
5-54	57.5	316
5-41	55	253
5-49	52.5	653
5-39	50	840
5-47	47.5	1,974
5-44	45	>12,307[b]
5-36	40	>10,097[b]
	1600 F	
5-50	23	1.4
5-45	22	2.[illegible]
5-58	21.5	29
5-60	21	44
5-37	20	47
5-53	19	243
5-59	18	993
5-48	17.5	2,339
5-55	16	8,974
5-38	15	>10,072[b]
	1800 F	
5-63	18.5	4.6
5-64	18	22
5-70	17.5	4.7
5-67	17	33
5-68	16	133
5-69	15	750
5-66	14	1,170
5-65	13	3,846
5-62	12.5	3,313
5-61	11.5	>17,160[b]

(a) .060-inch stress-relieved sheet; transverse specimens; R = 0.1.
(b) Specimen did not fail.

TABLE VII. RESULTS OF AXIAL-LOAD FATIGUE IN TESTS ON NOTCHED (K_t = 3.0) TD NICKEL SHEET[(a)] AT THREE TEMPERATURES

Specimen	Maximum Stress, ksi	Lifetime, kilocycles
	Room Temperature	
5-23	60	2.0
5-2	55	8.0
5-1	50	16
5-6	45	37
5-17	40	104
5-22	35	170
5-26	30	632
5-7	25	1,704
5-10	22.5	>10,067[(b)]
5-5	20	>12,567[(b)]
	1600 F	
5-11	22	1.3
5-4	20	5.7
5-9	17.5	27
5-27	15	104
5-12	14	190
5-3	12.5	271
5-14	11.5	808
5-15	11	3,800
5-8	10	>10,010[(b)]
	1800 F	
5-30	17	6.8
5-19	16	5.0
5-16	15	21
5-20	14	23
5-24	12	108
5-25	11	306
5-21	10	2,311
5-28	9	1,301
5-31	9	7,450
5-29	8	>17,004[(b)]

(a) .010-inch stress-relieved sheet, transverse specimens; R = 0.1.
(b) Specimen did not fail.

TABLE VIII. LINEAR EXPANSION OF TD NICKEL SHEET

Temperature, F	Expansion, percent
68	0
200	0.08_5
400	0.22_0
600	0.37_8
800	0.53_8
1000	0.71_5
1200	0.89_5
1400	1.08_5
1600	1.28_3
1800	1.48_8
2000	1.69_8

TABLE IX. MEAN LINEAR THERMAL-EXPANSION COEFFICIENTS FOR TD NICKEL SHEET

Temperature Range, F	Coefficient, in./in. F, $\times 10^{-6}$
68-200	6.4
68-400	6.8
68-600	7.2
68-800	7.5
68-1000	7.7
68-1200	7.9
68-1400	8.1
68-1600	8.3
68-1800	8.5
68-2000	8.7

TABLE X. STRESS-RUPTURE RESULTS FOR TD NICKEL SHEET[a] AT THREE TEMPERATURES

Specimen	Stress, ksi	Lifetime, hours
	1600 F	
3-1	16	0.6
3-2	14	4.5
3-4	12	37.5
3-6	10.5	245
3-9	9.5	493
3-13	8	>1488[b]
	1800 F	
3-3	10	13.9
3-5	8.5	62.6
3-7	8	86.9
3-8	6.2	888
3-17	5.2	>1056[b]
	2000 F	
3-10	7.5	2.5
3-11	5.3	104
3-15	5.2	>1320[b]
3-14	5.1	>1004[b]

(a) 0.060-inch stress-relieved sheet.
(b) Specimen did not fail.

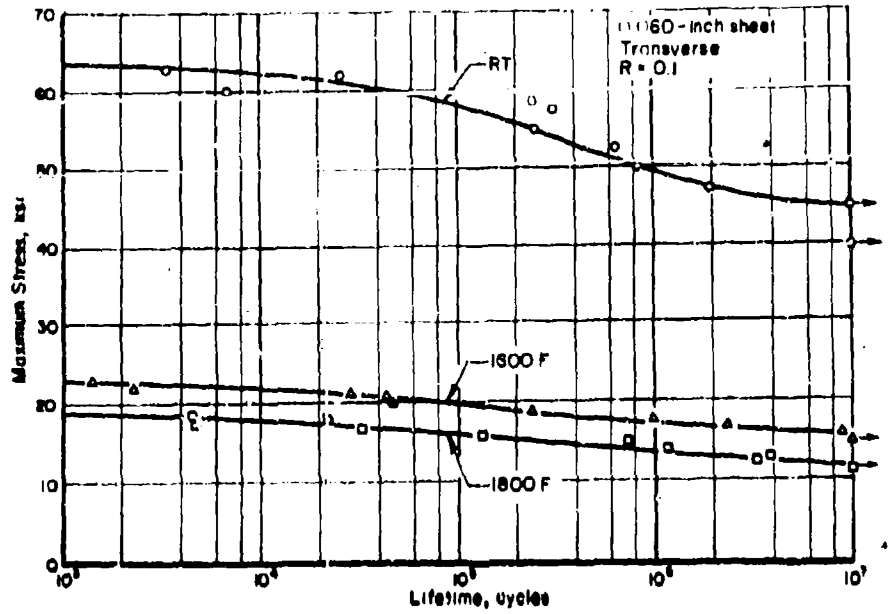

FIGURE 26. AXIAL-LOAD FATIGUE RESULTS FOR STRESS-RELIEVED TD NICKEL SHEET AT THREE TEMPERATURES

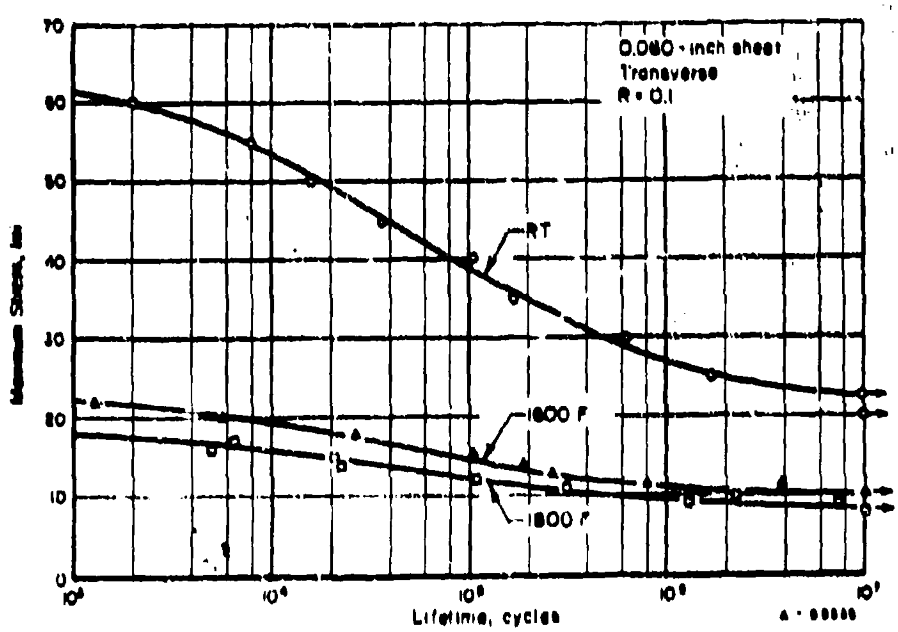

FIGURE 27. AXIAL-LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0), STRESS-RELIEVED TD NICKEL SHEET AT THREE TEMPERATURES

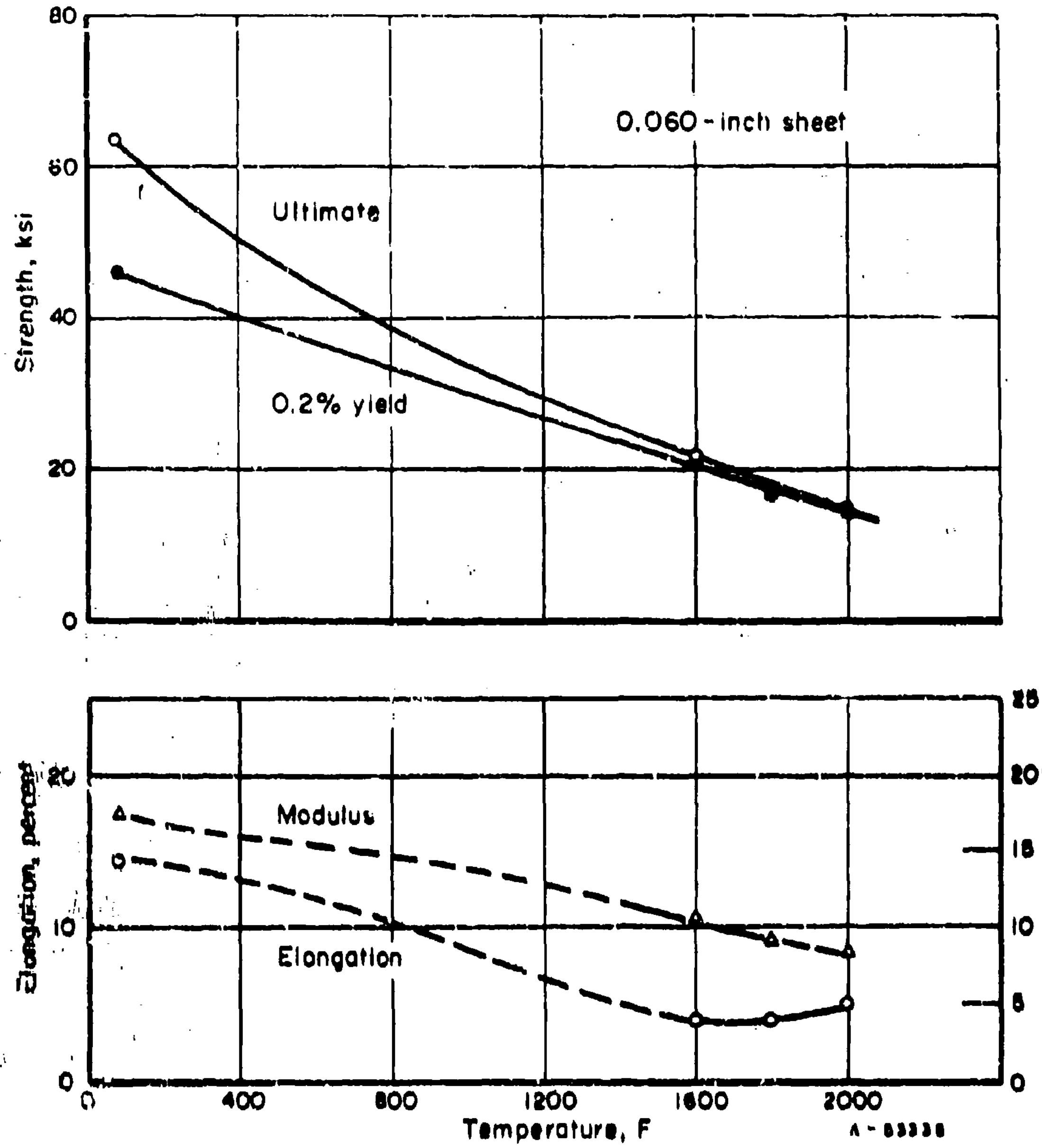

FIGURE 28. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF STRESS-RELIEVED TD NICKEL SHEET

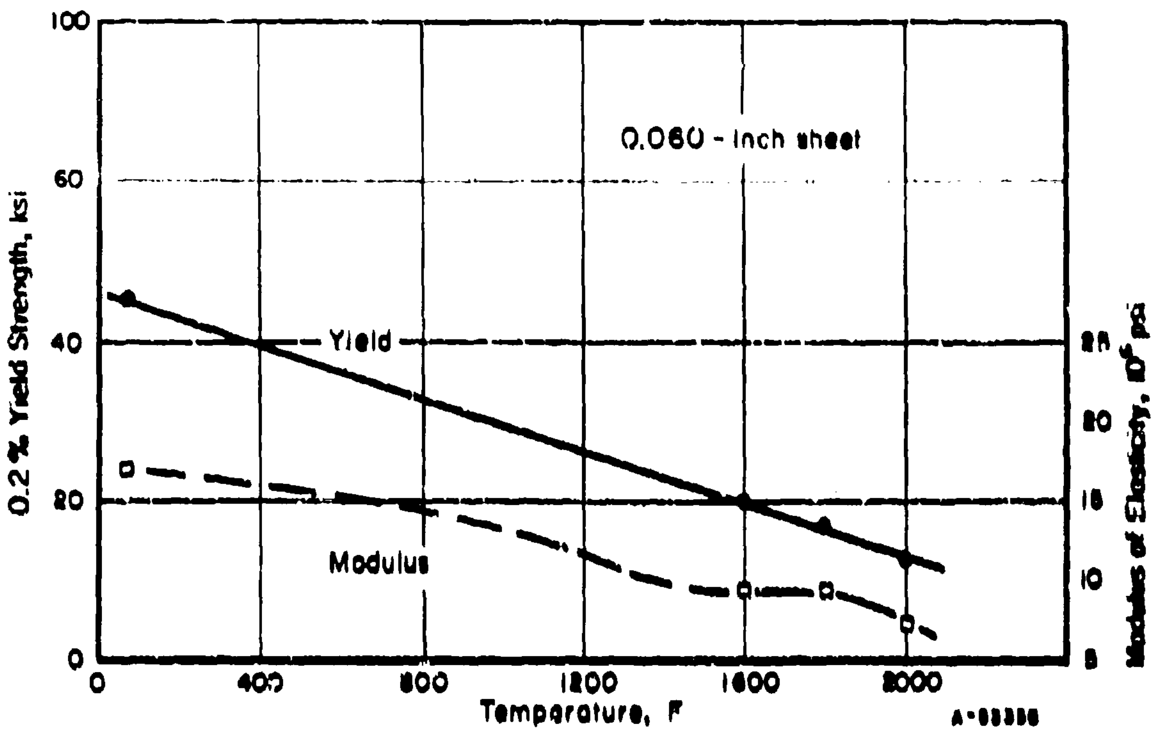

FIGURE 39. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF STRESS-RELIEVED TD NICKEL SHEET

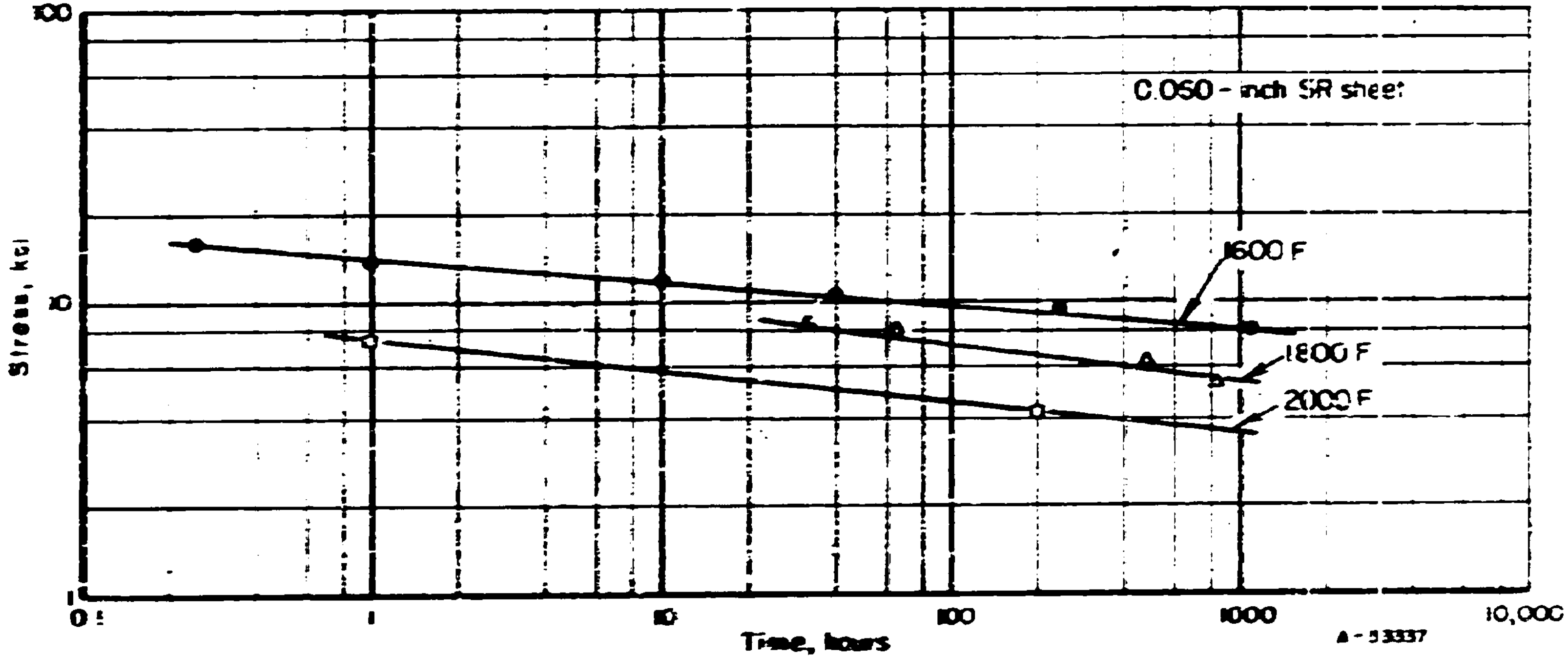

FIGURE 30. 0.?% DEFORMATION CURVES FOR TD NICKEL SHEET AT THREE TEMPERATURES

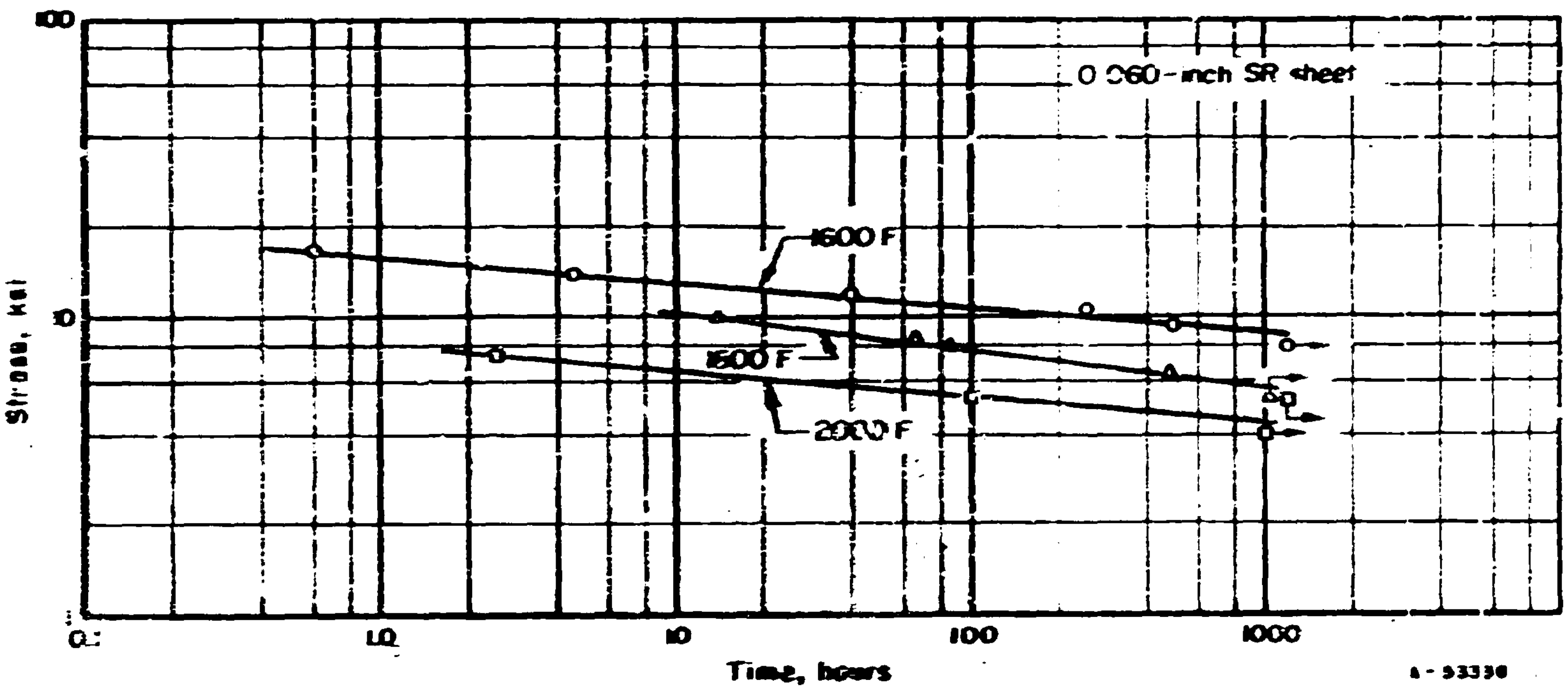

FIGURE 31. STRESS VERSUS RUPTURE TIME FOR TD NICKEL SHEET AT THREE TEMPERATURES

APPENDIX II

HP 9-4-25 PLATE DATA[a]

TABLE XI. DATA SHEET FOR HP 9-4-25 PLATE

Condition: 1025 F temper
Thickness: .25 inch

Properties	Temperature, F			
	RT	[illegible]	700	900
Tensile				
F_{tu} (longitudinal), ksi	197	182	165	138
F_{tu} (transverse), ksi	197	183	166	138
F_{ty} (longitudinal), ksi	184	161	146	123
F_{ty} (transverse), ksi	185	162	147	125
e_t (longitudinal), percent in 2 in.	15.1	15.8	15.0	15.7
e_t (transverse), percent in 2 in.	15.5	15.8	15.2	16.5
E_t (longitudinal), psi x 10^6	27.3	25.7	24.1	21.5
E_t (transverse), psi x 10^6	27.8	26.2	26.0	22.9
Compression				
F_{cy} (longitudinal), ksi	200	178	164	134
F_{cy} (transverse), ksi	197	178	164	134
E_c (longitudinal), ksi	30.1	28.7	27.7	25.7
E_c (transverse), ksi	28.9	27.7	26.4	24.8
Impact				
Charpy V-Notch, ft-lb(6)*	35-50	--	--	--
Fracture Toughness (K_{Ic})		--		--
Shear F_s				
(Longitudinal), ksi	128	--	--	--
(Transverse), ksi	128	--	--	--
Axial Fatigue				
10^3 (K_t = 1) (R = 0.1), ksi				--
10^5 (K_t = 1) (R = 0.1), ksi				--
10^7 (K_t = 1) (R = 0.1), ksi				--
10^3 (K_t = 3) (R = 0.1), ksi				--
10^5 (K_t = 3) (R = 0.1), ksi				--
10^7 (K_t = 3) (R = 0.1), ksi				--
Creep				
0.5% elongation 100 hr, ksi	--	--		
0.5% elongation 1000 hr, ksi	--	--		

TABLE XI. (Continued)

Properties	Temperature, F			
	RT	500	700	900
Stress Rupture				
Rupture 100 hr, ksi	--	--		
Rupture 1000 hr, ksi	--	--		
Stress Corrosion				
80 percent F_{ty} 1000 hr max		--	--	--
Coefficient of Thermal Expansion				
68 F to 800 F	6.4×10^6 in./in./°F (7)			
Density	0.28 lb./cu in. (7)			

*References are given on page 67.

(a) Data are average values.

TABLE XII. TENSILE RESULTS FOR HP 9-4-25 PLATE[a] AT FOUR TEMPERATURES

Specimen	0.2% Offset Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation in 2 Inches, percent	Tensile Modulus, psi x 10^6
		Longitudinal at Room Temperature		
1L-1	185	200	15.0	28.0
1L-2	184	196	15.5	27.4
1L-3	184	196	15.0	26.5
Average	184	197	15.1	27.3
		Transverse at Room Temperature		
1T-1	185	197	15.0	28.9
1T-2	184	197	16.0	27.3
1T-3	185	197	15.5	27.1
Average	185	197	15.5	27.8
		Longitudinal at 500 F		
1L-5	162	183	16.0	26.5
1L-6	160	180	15.5	25.7
1L-7	161	182	16.0	25.8
Average	161	182	15.8	25.7
		Transverse at 500 F		
1T-5	163	183	16.0	26.4
1T-6	162	183	16.0	26.2
1T-7	162	182	15.5	25.9
Average	162	183	15.8	26.2
		Longitudinal at 700 F		
1L-8	146	165	15.0	23.9
1L-9	147	165	15.0	24.6
1L-10	145	164	15.0	23.9
Average	146	165	15.0	24.1
		Transverse at 700 F		
1T-8	147	165	15.3	25.6
1T-9	148	167	15.3	26.1
1T-10	147	165	15.0	26.2
Average	147	166	15.2	26.0

TABLE XII. (Continued)

Specimen	0.2% Offset Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation in 2 Inches, percent	Tensile Modulus, psi x 10^6
		Longitudinal at 900 F		
1L-11	124	138	16.0	22.0
1L-12	123	138	15.7	21.1
1L-13	122	138	15.5	21.4
Average	123	138	15.7	21.5
		Transverse at 900 F		
1T-11	122	137	16.5	23.6
1T-12	123	138	16.8	23.0
1T-13	123	138	16.3	22.2
Average	123	138	16.5	22.9

(a) 1025 F temper; specimens ground to 0.22-inch thickness.

TABLE XIII. COMPRESSION RESULTS FOR HP 9-4-25 PLATE[a] AT FOUR TEMPERATURES

Specimen	0.2% Offset Yield Strength, ksi	Compression Modulus, psi x 10^6
	Longitudinal at Room Temperature	
2L-1	200	30.0
2L-2	200	30.1
2L-3	200	30.1
Average	200	30.1
	Transverse at Room Temperature	
2T-1	198	28.9
2T-2	197	28.9
2T-3	197	29.0
Average	197	28.9
	Longitudinal at 500 F	
2L-4	178	28.4
2L-5	179	28.9
2L-6	178	28.7
Average	178	28.7
	Transverse at 500 F	
2T-4	179	27.6
2T-5	177	27.6
2T-6	177	27.8
Average	178	27.7
	Longitudinal at 700 F	
2L-7	164	28.0
2L-8	163	28.0
2L-9	165	27.0
Average	164	27.7

TABLE XIII. (Continued)

Specimen	0.2% Offset Yield Strength, ksi	Compression Modulus, psi x 10^6
	Transverse at 700 F	
2T-7	164	26.7
2T-8	164	25.8
2T-9	164	26.8
Average	164	26.4
	Longitudinal at 900 F	
2L-10	133	26.6
2L-11	134	25.0
2L-12	134	25.4
Average	134	25.7
	Transverse at 900 F	
2T-10	135	25.2
2T-11	133	24.8
2T-12	133	24.4
Average	134	24.8

(a) 1025 F temper; specimens ground to 0.22-inch thickness.

TABLE XIV. SHEAR TEST RESULTS FOR HP 9-4-25 PLATE[a] AT ROOM TEMPERATURE

Specimen	Ultimate Shear Strength, ksi
Longitudinal	
4L-1	129
4L-2	128
4L-3	128
Average	128
Transverse	
4T-1	131
4T-2	127
4T-3	125
Average	128

(a) 1025 F temper; specimens ground to 0.22-inch thickness.

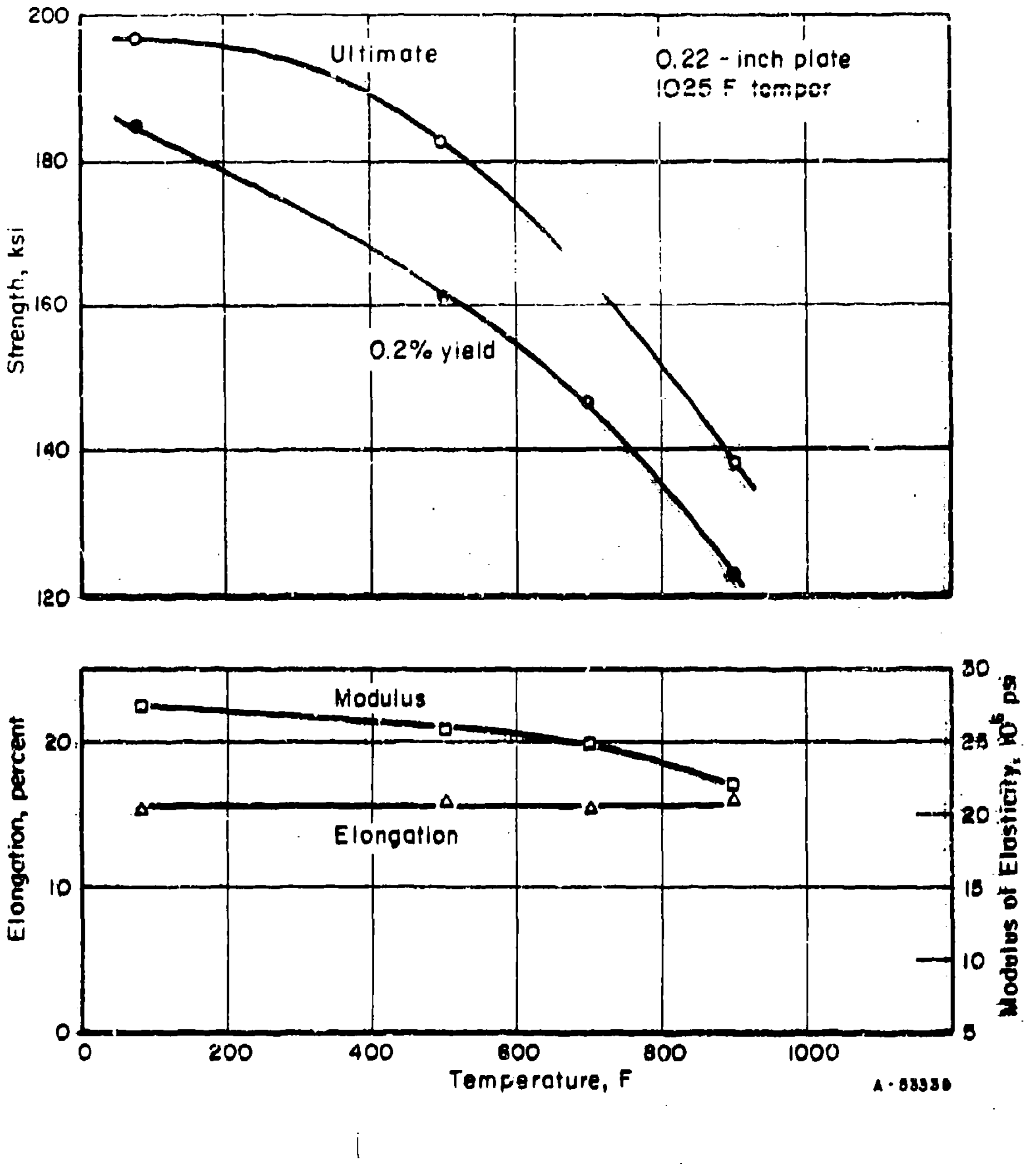

FIGURE 32. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF HP 9-4-25 PLATE

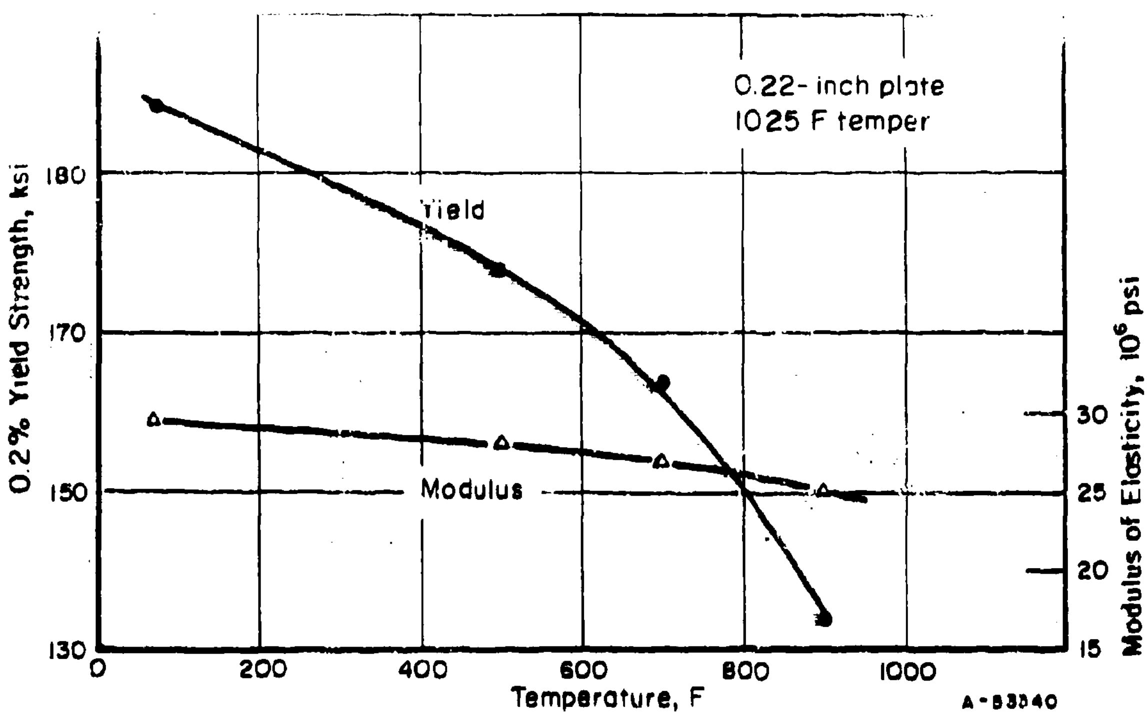

FIGURE 33. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF HP 9-4-25 PLATE

APPENDIX III

HP 9-4-45 DATA[a]

TABLE XV. DATA SHEET FOR HP 9-4-45 PLATE

Condition: Bainitic
475 F 6-8 hr
Thickness: .25 inch

Properties	Temperature, F RT	300	500	--
Tensile				
F_{tu} (longitudinal), ksi	270	272	234	--
F_{tu} (transverse), ksi	268	271	235	--
F_{ty} (longitudinal), ksi	222	196	167	--
F_{ty} (transverse), ksi	224	197	166	--
e_t (longitudinal), percent in 2 in.	10.7	13.2	16.5	--
e_t (transverse), percent in 2 in.	10.0	11.6	15.7	--
E_t (longitudinal), psi x 10^6	27.1	26.8	24.6	--
E_t (transverse), psi x 10^6	27.7	26.6	24.9	--
Compression				
F_{cy} (longitudinal), ksi	249	219	187	--
F_{cy} (transverse), ksi	251	224	192	--
E_c (longitudinal), ksi	29.3	28.4	27.9	--
E_c (transverse), ksi	29.2	28.2	27.3	--
Impact				
(charpy v-notch, ft-lb (6)*	16-22	--	--	--
Fracture Toughness (K_{Ic})		--		--
Shear F_s				
(longitudinal), ksi	159	--	--	--
(transverse), ksi	159			
Axial Fatigue				
10^3 (K_t=1) (R=0.1), ksi				--
10^5 (K_t=1) (R=0.1), ksi				--
10^7 (K_t=1) (R=0.1), ksi				--
10^3 (K_t=3) (R=0.1), ksi				--
10^5 (K_t=3) (R=0.1), ksi				--
10^7 (K_t=3) (R=0.1), ksi				
Creep				
0.5% elongation 100 hr, ksi	--			
0.5% elongation 1000 hr, ksi	--			

TABLE XV. (Continued)

Properties	Temperature, F			
	RT	300	500	--
Stress Rupture				
Rupture 100 hr, ksi	--			--
Rupture 1000 hr, ksi	--			--
Stress Corrosion				
80 percent F_{ty} 1000 hr max		--	--	--
Coefficient of Thermal Expansion				
68 to 800 F	6.2×10^{-6} in./in./°F (7)			
Density	0.28 lb/cu in. (7)			

* References are given on page 67.
(a) Data are average values.

TABLE XVI. TENSILE RESULTS FOR HP 9-4-45 PLATE[a] AT THREE TEMPERATURES

Specimen	0.2% Offset Yield Strength, ksi	Ultimate Tensile Strength, ksi	%Elongation in 2 Inches, percent	Tensile Modulus, psi x 10^6
		Longitudinal at Room Temperature		
1L-1	222	275	9.0	27.0
1L-2	222	268	12.0	27.2
1L-3	223	268	11.0	27.1
Average	222	270	10.7	27.1
		Transverse at Room Temperature		
1T-1	223	268	10.0	27.6
1T-2	223	268	10.0	28.1
1T-3	225	268	10.0	27.5
Average	224	268	10.0	27.7
		Longitudinal at 300 F		
1L-5	197	271	15.0	26.8
1L-6	195	272	11.0	26.8
1L-7	196	272	13.5	26.7
Average	19[illegible]	272	13.2	26.8
		Transverse at 300 F		
1T-5	197	27[illegible]	11.2	26.4
1T-6	195	271	11.5	26.9
1T-7	200	271	12.0	26.4
Average	197	271	11.6	26.6
		Longitudinal at 500 F		
1T-8	169	235	16.5	23.9
1T-9	168	235	16.5	24.6
1T-10	163	233	16.5	25.3
Average	167	234	16.5	24.6

TABLE XVI. (Continued)

Specimen	F_{ty}	F_{tu}	e_t	E_t
		Transverse at 500 F		
1T-8	167	237	15.7	24.4
1T-9	166	235	15.7	25.5
1T-10	166	234	15.7	24.8
Average	166	235	15.7	24.9

(a) 475 F temper; specimens ground to 0.22-inch thickness.

TABLE XVII. COMPRESSION RESULTS FOR HP 9-4-45 PLATE[a] AT THREE TEMPERATURES

Specimen	0.2% Offset Yield Strength, ksi	Compression Modulus, psi x 10^6
	Longitudinal at Room Temperature	
2L-3	249	29.1
2L-11	249	29.3
2L-12	249	29.4
Average	249	29.3
	Transverse at Room Temperature	
2T-1	251	29.3
2T-2	251	29.3
2T-3	251	29.1
Average	251	29.2
	Longitudinal at 300 F	
2L-4	220	28.6
2L-5	217	28.5
2L-6	220	28.2
Average	219	28.4
	Transverse at 300 F	
2T-4	224	28.2
2T-5	223	28.5
2T-6	224	28.0
Average	224	28.2
	Longitudinal at 500 F	
2L-7	183	27.7
2L-8	188	28.3
2L-9	190	27.7
Average	187	27.9
	Transverse at 500 F	
2T-7	194	27.1
2T-8	190	27.4
2T-9	192	27.4
Average	192	27.3

(a) 475 F temper; specimen ground to 0.22-inch thickness.

TABLE XVIII. SHEAR TEST RESULTS FOR HP 9-4-45 PLATE[a] AT ROOM TEMPERATURE

Specimen	Ultimate Shear Strength, ksi
Longitudinal	
4L-1	157
4L-2	161
4L-3	158
Average	159
Transverse	
4T-1	161
4T-2	158
4T-3	159
Average	159

(a) 475 F temper; specimens ground to 0.22-inch thickness.

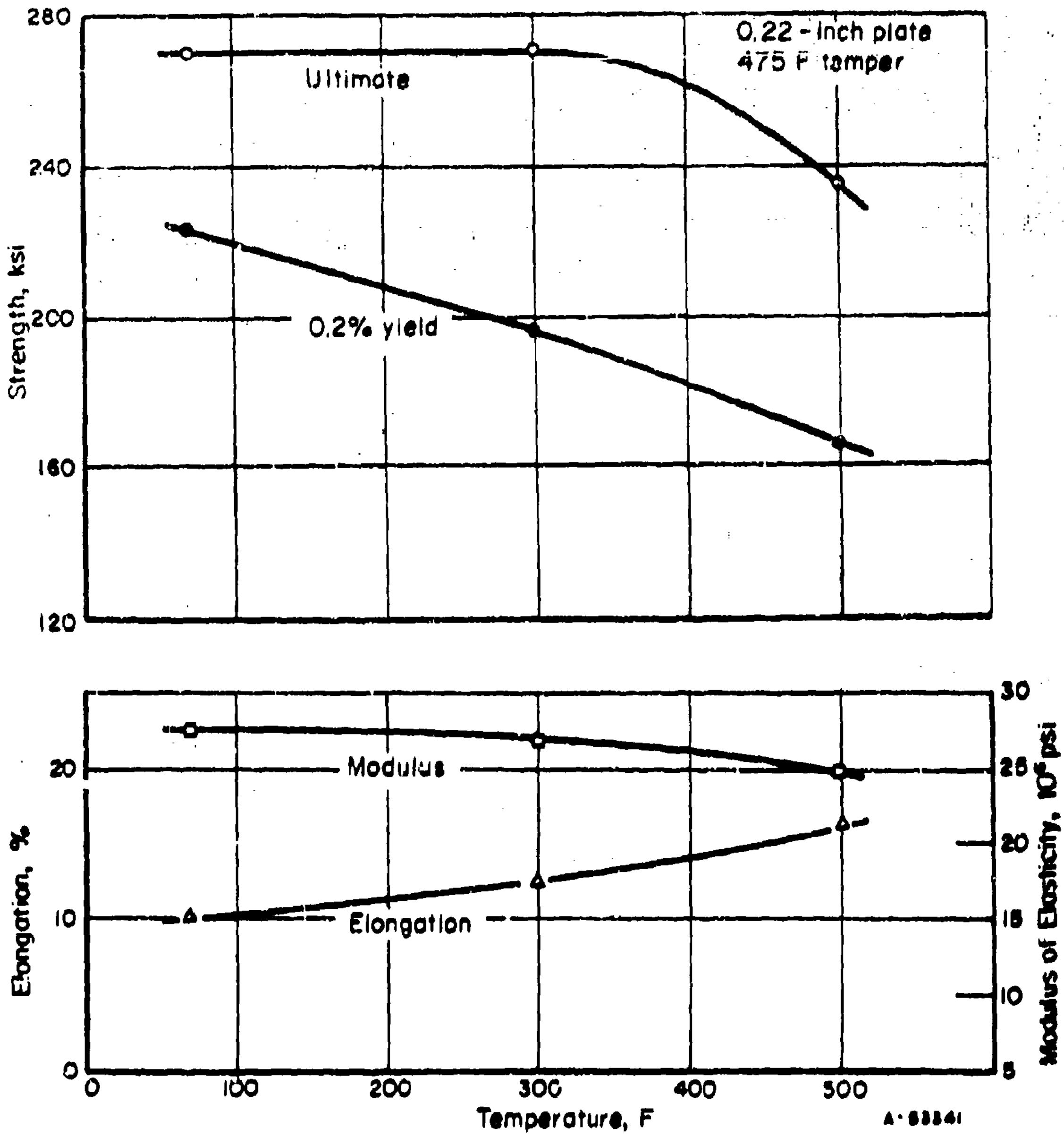

FIGURE 34. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF HP 9-4-45 PLATE

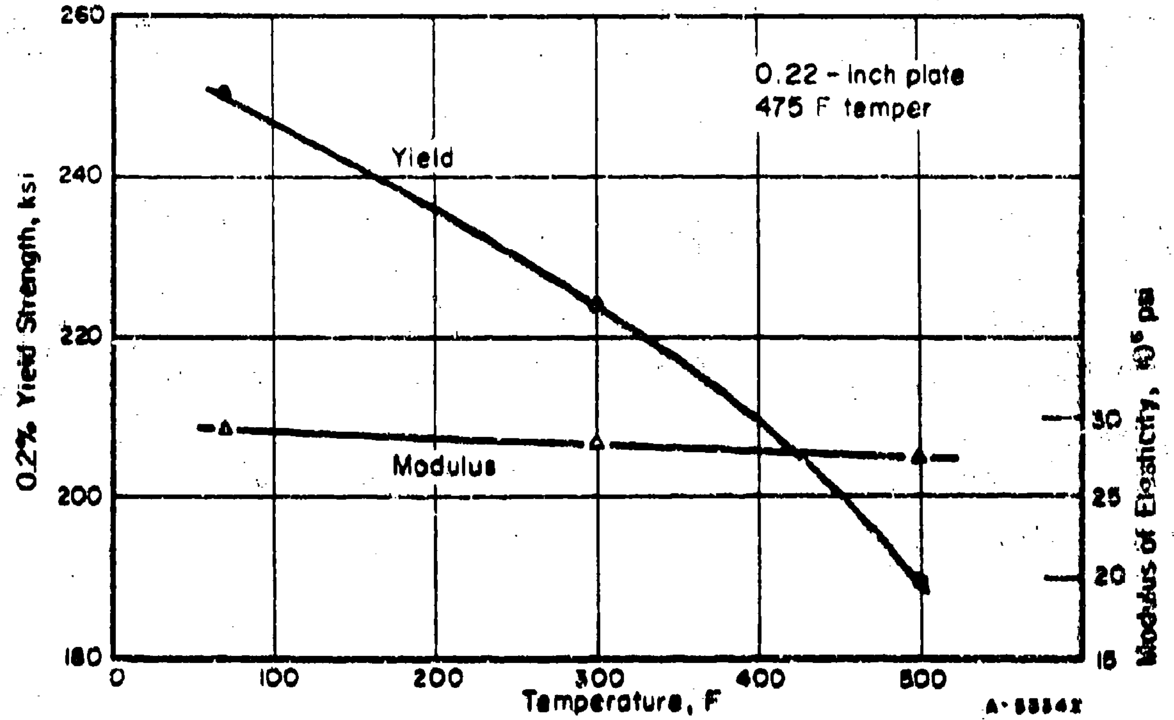

FIGURE 35. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF HP 9-4-45 PLATE

IV

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13. ABSTRACT

The major objectives of this research program are to evaluate newly developed structural materials of potential Air Force weapons system interest and then to provide data-sheet-type presentations of mechanical data. The first year's effort covered in this report, has concentrated on TD nickel, HP 9-4 steels, AFC77 steel, and Lockalloy (62Be-38Al).

The mechanical properties investigated included tensile, compression, shear, bend, fracture toughness, fatigue, creep, and stress corrosion at appropriate temperatures.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Mechanical properties						
Chemical composition						
Corrosion resistance						
Physical properties						
Thoria-strengthened nickel						
High-strength steel						
Stainless steel						
Beryllium alloy						
Rolling						
TD Nickel						
HP 9-4						
AFC-77						
Lockalloy (62Be-38Al)						